Summer 8-14-2015

Electronic Health Record Optimization for Cardiac Care

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Electronic Health Record Optimization for Cardiac Care

by

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A DISSERTATION

Presented to the Faculty of

The University of Nebraska Graduate College

In Partial Fulfillment of the Requirements

For the Degree of Doctor of Philosophy

Biomedical Informatics
Graduate Program

Under the Supervision of Professor John R. Windle

University of Nebraska Medical Center
Omaha, Nebraska

June, 2015

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Abstract

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Electronic health record (EHR) systems have been studied for over 30 years, and despite the benefits of information technology in other knowledge domains, progress has been slow in healthcare. A growing body of evidence suggests that dissatisfaction with EHR systems was not simply due to resistance to adoption of new technology but also due to real concerns about the adverse impact of EHRs on the delivery of patient care. Solutions for EHR improvement require an approach that combines an understanding of technology adoption with the complexity of the social and technical elements of the US healthcare system. Several studies are presented to clarify and propose a new framework to study EHR-provider interaction. Four focus areas were defined - workflow, communication, medical decision-making and patient care. Using Human Computer Interaction best practices, an EHR usability framework was designed to include a realistic clinical scenario, a cognitive walkthrough, a standardized simulated patient actor, and a portable usability lab. Cardiologists, fellows and nurse practitioners were invited to participate in a simulation to use their institution's EHR system for a routine cardiac visit. Using a mixed methods approach, differences in satisfaction and effectiveness were identified. Cardiologists were dissatisfied with EHR functionality, and were critical of the potential impact of the communication of incorrect information, while displaying the highest level of success in completing the tasks. Fellows were slightly less dissatisfied with their EHR interaction, and demonstrated a preference for tools to improve workflow and support decision-making, and showed less success in completing the tasks in the scenario. Nurse practitioners were also dissatisfied with their EHR interaction, and cited poor organization of data, yet demonstrated more success than fellows in successful completion of tasks. Study results indicate that requirements for EHR functionality differ by type of provider. Cardiologists, cardiology fellows, and nurse practitioners required different levels of granularity of patient data for use in medical decision-making, defined different targets for communication, sought different solutions to workflow which included distribution of data input, and requested technical solutions to ensure valid and relevant patient data. These findings provide a foundation for future work to optimize EHR functionality.

Chapter I - Introduction

Overview

Current medical practice embraces the use of information technology as a means to provide better patient care. In particular, the electronic health record (EHR) has long been expected to transform the delivery of health care services in the United States, reducing costs and improving health outcomes by standardizing practice to improve productivity and reduce medical errors. EHR systems have been studied in depth for over 30 years. Information technology increased productivity in industries such as mining, manufacturing, finance, and additionally, improved safety in more complex knowledge domains such as nuclear power and aerospace [1,2]. Despite these advancements, progress has been slow in the adoption and acceptance of information technology within the context of health care. Understanding the nature of this gap between the potential benefits to health outcomes through the use of technology and the ease of use of EHR systems is the focus of this thesis.

The trajectory of EHR adoption

The capture of patient data is important to the practice of medicine. By the 4th century BC, careful observation of patients and subsequent note-taking created early case histories. As part of the Hippocratic Corpus, these documents established the value of historic patient data as a foundation of western medicine [3]. In the 16th century, as interest in the scientific method grew, medical practitioners began to publish collections of individual cases, which were used for training of physicians. Paper records began to be used by clinicians in the late 1800's to capture observations and recommendations to better care for patients over time [4,5]. Medical knowledge expanded rapidly as a result of two world wars, necessitating the recording of patient data to allow for better outcomes in battlefield survival. In the 1940's, patient data began to be viewed as an important component for the management of health in populations [6]. Innovative approaches to capturing and analyzing patient health information were developed out of necessity to address a postwar physician shortage. Allowing nurses and other team members to conduct tests and gather data allowed physicians more time to focus on care for sick patients. The multi-phasic health checkup, developed by Kaiser Permanente, was given to thousands of members to screen for conditions such as heart disease, diabetes, and cancer [7].

The introduction of digital computers in the early 1940's began to transform industries such as manufacturing, banking, and transportation. Healthcare applications began to appear, and the introduction of electronic health records began in the 1960's, with customized systems developed by visionaries like Morris Collen of Kaiser Permanente, to store and organize the vast amount of data collected from its members [7]. Early versions of hospital information systems began to be developed, using innovative approaches to medical data. Massachusetts General developed a programming framework specifically for the complexity of medical information, Massachusetts General Hospital Utility Multi-Programming System (MUMPS) [6]. At the same time, innovative approaches to the organization of medical information based on the problem-oriented medical record were suggested [8].

Computing migrated from mainframe to personal computers in the 1970's, providing greater opportunity for individuals, departments, and institutions to develop their own customized versions of a system to capture and retrieve patient information. Beginning in the 1980s, commercial versions of electronic health record (EHR) systems began to be introduced, such as General Electric's Centricity, and the Department of Defense's Veterans Health Information Systems and Technology Architecture (VistA), which further expanded the capture of digital health data. The need for integration of patient data within the context of a patient visit expanded as medical care moved from primary to specialty care, and the sheer volume of clinical information grew larger. A new generation of commercial EHR products became available, aimed at more efficient methods of organizing patient data into useful information to improve efficiencies and safety in healthcare [9].

Efforts to promote EHR adoption and use began to focus on policy-directed, top-down approaches. Elimination of paper patient records was first recommended in 1991, in a report published by the Institute of Medicine that encouraged paperless records within 10 years [10]. The Office of the National Coordinator for Health Information Technology (ONC) was created in 2004 by then President George W. Bush to pursue the nation-wide use of EHR by 2014 [11]. In 2005, researchers from the RAND Corporation, a nonprofit research institution that helps improve policy and decision-making, projected annual savings of more than $80 billion through the accelerated adoption of health information technology. This led optimistic macro-efforts to incentivize adoption through governmental policy for economic benefits [12,13], or for better healthcare quality [14]. Organizations such as the Agency for Healthcare Research and Quality (AHRQ), the Joint Commission for the Accreditation of Healthcare Organizations (OCAHO), the National Library of Medicine, and the National Patient Safety Foundation were created to oversee and fund research to explore the use of information technology to address public health issues [9]. As part of the American Recovery and Reinvestment Act of 2009, the Health Information Technology for Economic and Clinical Health (HITECH) Act was introduced by President Barack Obama to further promote adoption [15-17]. The Centers for Medicare and Medicaid Services established financial incentives for “meaningful use” of EHR systems, including electronic documentation, prescribing, and clinical decision support [18,19]. Despite these efforts, a 2013 revisit by RAND indicated that adoption rates of 40% of US physicians and

27% of hospitals fell far short of the 90% predicted in the earlier article. In addition, quality and efficiency of care were seen to be declining, while healthcare expenditures grew to $2.8 trillion [20]. Recommendations included top-down approaches to interoperability, but also included user-focused approaches to issues of patient-centeredness and ease of use.

Expectations for the application of information technology rose, and studies of EHR adoption and acceptance rapidly followed. Many factors were found to negatively impact adoption, and included the high costs of software, the lack of standardization by EHR vendors and EHR interfaces that were not integrated smoothly into clinician workflow [21-26]. A bias toward administrative rather than clinical functionality in the design of EHR systems was seen in the dissatisfaction of clinical users with the negative impact of current EHRs on workflow and communication [27]. While some evidence indicated that EHR systems improved access to information, contradictory findings highlighted the difficulty in assessing the progress that was made since the introduction of EHR systems [28,29].

The relationship between user workflow and EHR information flow was studied, revealing a need for understanding the context for EHR use, and the role of domain differences in EHR design [30,31]. Physicians' dissatisfaction with inefficient workflow and information flow between clinical users was motivated by potential negative impacts on the quality of patient care [32].

The gap

Understanding of the principles of adoption and acceptance of EHR systems has expanded, yet there is little confirmation that EHR systems deliver functionality to meet the needs of clinical users. Nearly 40 years of history of EHR implementation has revealed that barriers to adoption are cultural, economic and structural, and that challenges will be met by applying what has been learned from the rich history of adoption studies [33]. In the current environment of 2014, use of EHR systems has been incentivized through "meaningful use", a program administered through the Centers for Medicare & Medicaid Services (CMS) to stimulate the use of certified electronic health record (EHR) technology to improve the quality, safety, efficiency and coordination of healthcare practices while maintaining the privacy of patient health data [157]. EHR adoption has increased at a rapid pace, with 94% of hospitals using some form of EHR system, and physician adoption at 75% [34,35]. Despite increased usage, concerns for patient safety continue to contribute to the dissatisfaction of providers [36-38]. These concerns pushed the focus of EHR research beyond issues of adoption to more complex issues requiring an understanding of the interaction between providers, patients, and the EHR systems they must use.

Cardiovascular disease

Cardiovascular disease is the leading cause of death in the US, with nearly 600,000 deaths per year [39]. Death rates for cardiovascular disease have declined substantially since 1999, 44% due to lifestyle and environmental changes, and 47% due to increased use of evidence-based medical therapy [40]. Yet nearly 40% of US citizens are projected to have some form of cardiovascular disease by 2030, and estimated costs for treatment are projected to grow to nearly $1.5 trillion [41].

Description of the study

The focus of this mixed methods study is to explore the development of an EHR evaluation framework that can be used in a simulated inpatient environment to measure EHR use by cardiology fellows and faculty at two independent medical centers. It was hypothesized that substantial differences in EHR usability, specifically efficiency, effectiveness and satisfaction, can be detected using a Human-Computer Interactions (HCI) framework, which includes a realistic clinical scenario, a mobile evaluation toolkit, and a cognitive walkthrough. This hypothesis was formed from the findings of the studies that have been described above, which identified gaps in widely implemented EHR systems.

There were four components to this research necessary to achieve this objective. First, it was vital to explore the meaning of usability through the eyes of the users, i.e., providers, which is described in Chapters 3 and 4. Secondly, it was necessary to identify a method flexible enough to assess usability in various real-world clinical settings, which is described in Chapter 5. In the third component of the research, the hypothesis was tested using a robust clinical scenario, the HCI-derived method of cognitive workflow, and a mobile usability lab. The research concluded with the fourth component, the specification of user-designed requirements for optimized EHR systems design. The study and findings are presented in Chapter 6. Detailed discussions of chapters are contained below.

Chapter 2 presents the conceptual foundations for this research, which can be divided into 4 categories, which are introduced below, and discussed later in detail:

1) Diffusion of Innovation. The theory of diffusion of innovation was introduced in the 1960's. From the domain of sociology, it describes the process by which a new concept is communicated through different channels by members of a social system. Specifically, the theory explores the resistance to adoption of new ideas within a social community. Diffusion study started with the study of seed corn adoption among Iowa farmers in the 1950's, but the concepts were seen to broadly apply to many types of innovation – social policy, education, public health, communication, marketing, and technology. From a rich foundation, DOI theory includes structures to explain the process of adoption, as well as issues that accompany change.

2) Socio-technical systems theory. The relationship between the social aspects of humans and societies, and the technical aspects of organizational structures and business processes is explored through socio-technical systems theory, which was created within the domain of systems engineering. Early studies of English coal miners led to a theory to describe the often contradictory elements of efficiency and human nature within a system. Research in this area has expanded to deal with the increasing complexity of systems, and the challenges that still exist in balancing the social, technical, cultural and professional environments within a system.

3) Human-computer interaction. The domain of human-computer interaction (HCI) provides tools for understanding the interaction between humans and computers, which takes place through a system's user interface. HCI explores the design, evaluation, and implementation of interactive computing systems and the study of major phenomena surrounding the use of the system. It also prescribes techniques, methods, and guidelines for designing better and more "usable" interfaces that support the interaction between human and system.

4) Mixed methods studies. Combining qualitative and quantitative research methods allows a pragmatic approach to answering complex research questions, where either method alone may prove insufficient. Mixed methods studies use a variety of collection and analysis methods to reveal new insights and generate new themes or variables for further inquiry.

Chapter 3 investigates the perspectives of different groups of administrative and clinical stakeholders toward the adoption of EHR systems [42]. While EHR systems are believed to improve access to information, contradictory findings highlight the difficulty in assessing the progress that has been made since the introduction of EHR systems. This qualitative study examines physician resistance as a key factor in the adoption of technology within the clinical setting. Focus group sessions with academic and private physicians and administrators were conducted to explore their differing perspectives on the use of technology to support patient care. Transcripts of the sessions were analyzed using grounded theory with investigators trained in medicine and social sciences. Patterns were identified and compared to build themes between and across the four study groups.

Major themes emerged from the analysis, and included the impact of EHR systems on workflow, patient care, communication, research/outcomes/billing, education/learning, along with the influence of EHR on institutional culture. The academic and private physicians included in the study were confident of the future benefits of EHR systems, but expressed concern about current implementations of EHR for potential negative impacts on interaction with patient, and with other members of the healthcare team. They also suggested that an increasing amount of time was necessary to complete documentation to adequately represent the details of the patient visit. In sharp contrast, administrators were generally positive and optimistic about the value of the EHR in managing patient care. Results of this study concluded that provider resistance is not based on commonly held perceptions about resistance to change, high EHR investment costs and threats to patient data, but that EHR functionality was insufficient to support timely and accurate documentation. More importantly, physician perceived that the EHR could negatively impact patient care. These findings indicated that further study was needed to explore gaps related to issues of workflow and patient safety.

Chapter 4 investigates the benefits and clarifies the limitations of the use of two mature, robust, comprehensive EHR systems by a group of technically skilled physicians who were required to use their institution's EHR to care for patients. These subjects were considered super-users within their institutions, eliminating resistance to technology as a barrier to adoption. Each of the two institutions studied had EHR systems in place for over 20 years.

Utilizing the research design from the earlier study, focus groups were conducted with residents and faculty members who practiced at both institutions. Open ended questions were designed to better understand EHR interaction and perceptions of EHR benefits and limitations. Findings indicated that physicians believed the EHR had an adverse impact on two specific aspects of patient care, physician workflow and team communication. Both systems had perceived strengths but also significant limitations and neither were able to satisfactorily address all of the physicians' needs. The study concluded that difficulties related to physician acceptance were characterized by their real concerns about the impact of EHR use on patient care. Physicians were optimistic about the future benefits of EHR systems, but they continued to be frustrated with the non-intuitive interfaces and cumbersome data searches of existing EHRs, indicating that human computer interaction, specifically the study of usability, might provide clues to mediate the gaps that were identified by the participants.

Chapter 5 investigates the use of a mobile evaluation lab to collect objective and subjective data on EHR usability – through the study of provider/EHR interactions. EHR usability research contains a long history of survey-oriented research, but few studies successfully represent the real-world clinical environment and complexity of provider's tasks and workflows. Understanding physician cognitive workflow while using an EHR and how the user interface interaction supports provider tasks is essential to improving EHR usability. The usability evaluation method was novel in its inclusion of users in a realistic context, rather than a more typical, top-down information technology viewpoint.

The multi-faceted usability evaluation design included a portable usability lab, a complex scenario, and a set of well-established usability measurements. During a cognitive walkthrough, the lab was successfully used to collect video, audio and keystroke data from the user screen interaction and audio data from the users' "think aloud" comments. This data was combined with field notes that captured task completion times, task success and nonverbal user feedback. The study demonstrated that EHR usability studies are possible in a real-world cardiac care setting, and established a method for future studies.

Chapter 6 proposes a novel method to determine the usability of the electronic health record, and measured providers' perceptions of efficiency, effectiveness and satisfaction. Improving the acceptance and use of EHR systems is more than an exercise to improve existing functionality. The use of a robust clinical scenario, the stepwise method of cognitive task analysis, and a mobile usability lab provide a framework that identifies requirements based on provider's needs. The research concluded with a provider-based set of requirements for EHR usability that serve as useful input to the design of optimized EHR systems.

In this research, it was hypothesized that substantial differences in EHR usability, specifically measures of efficiency, effectiveness and satisfaction, can be detected using a Human-Computer Interactions (HCI) framework, including a realistic clinical scenario, a mobile evaluation toolkit, and a cognitive walkthrough. This framework supports the creation of innovative designs that leapfrog current limitations of how technology can be used in patient care.

Chapter 2 – Review of Literature

Introduction

Understanding the history of EHR adoption, and the difficulties in assessing the needs of a diverse group of EHR users provides a foundation for moving beyond the current barriers of dissatisfaction for providers and patients. This includes a review of prior research to understand how innovations are accepted within social systems, the complexity of technology impacts on social systems, measurement schemas to assess the success of human interactions with technology, and the active and frequent involvement of users in the design of technology that they will subsequently use. The chapter concludes with a review of mixed method study design to overcome the barriers that have been identified.

Diffusion of Innovations

Diffusion of Innovations is a theoretical concept proposed by Everett Rogers, a rural sociologist, to explain how new and innovative ideas are adopted by a social system [43]. Originally posed as an answer to why farmers in Carroll, Iowa in the 1950's were hesitant to purchase newly developed hybrids of seed corn that had obvious economic advantages, DOI has been widely adopted to frame discussions of many different types of innovations, and many different social contexts beyond its roots in agriculture. Based heavily on communication theory (sender-message-channel-receiver-effect), Rogers extended his original work to a more general theory, which clarified the similarities across cultures, different types of innovations, and the personalities of adopters.

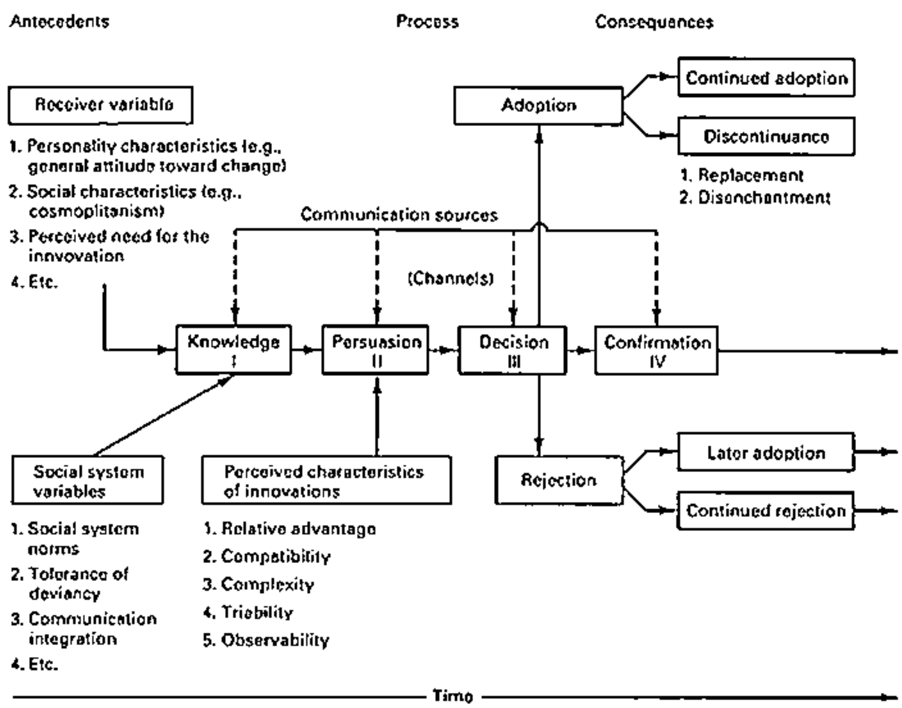


Figure 1. Diffusion of innovation model (Rogers, 1995 [43])

The process of diffusion is defined by the complex interrelationship of time, communication, and social systems, as shown in Figure 1. It is the process in which an innovation is conveyed through various communication channels over a period of time and accepted among the members of a social system who hold similar cultural values. The theory explains social change, or often, the reasons for resistance to social change, which can occur in other ways, such as government policy, political change (such as war or revolution), or natural events (breakout of infectious disease, climate change).

The decision to adopt an innovation is described by the usually linear relationship of knowledge, persuasion, decision and confirmation. Knowledge represents the entry point to the process of adoption, in which an individual first learns about an innovation. The individual's personal characteristics, including their perception of need, as well as their social system, influence their readiness to begin the process of adopting a new idea. Persuasion occurs when the individual begins to form an attitude toward the innovation, and can be influenced by the characteristics of the innovation, which will be discussed further below. This drives the individual to take actions that lead to a decision to adopt or reject the innovation. Confirmation allows the individual to feel good about the decision and promote it to others, or to change it based on unfavorable feedback.

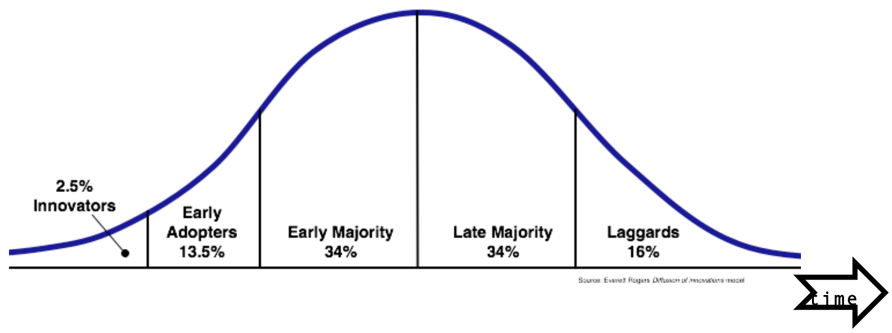


Figure 2. Technology Adoption Curve (adapted from Rogers, 1995 [43])

Figure 2 depicts the process in which an innovation is conveyed through various communication channels over a period of time and accepted (or rejected) among the members of a social system who hold similar cultural values. Different categories of adopters are defined based on how early an individual will choose to adopt a new idea. Innovators are a small group, characterized by an obsession with daring and risky ideas. They are the entry point of a new idea into the social system, and they are able to deal with a high level of uncertainty about the success of the innovation. Early adopters are seen as the opinion leaders within the social system, and are respected as decision-makers who decrease the level of uncertainty about the innovation by adopting it, and spreading the news to other members of the system. The majority is broken into early and late majority, and composes the largest segments of the curve. The early majority interacts with and trusts the judgment of the early adopters. However, even with the high level of trust, they take the longest time in innovation-decision making. This group also serves as the conduit to pull the later adopters into a new idea. The late majority is highly risk averse and makes a decision after the average member of the social system has adopted. Laggards are suspicious of change and will adopt only after the innovation has been proven.

Extensive research accompanies the socioeconomic, personality and communication characteristics of these groups, and provides a set of generalizations. For instance, earlier adopters are more educated or literate, earlier adopters are more able to think abstractly, and earlier adopters have greater interaction within their social community, which can be used as a framework to increase the success of a new idea, product, or policy.

The early adopter holds the highest degree of opinion leadership in most systems. The decision to adopt is influenced by champions or opinion leaders who can change the attitude of others. The sustainability of diffusion is reached at critical mass, or the "tipping point". The recipe for getting to critical mass:

1. Identify influential individuals within the social system and engage them at the beginning of the quest for adoption
2. Convince individuals by crafting the message that adoption is already occurring
3. Find groups who are characteristically more receptive to innovation
4. Provide liberal incentives until critical mass is reached.

The rate of adoption is influenced by five attributes which include relative advantage – the degree to which this innovation is superior to the previous idea; compatibility – how closely the innovation relate to the values, experience and needs of the user; complexity – how difficult it is to understand and to use; trialability – whether the user can experiment with the innovation without commitment, and observability – whether the results of the innovation are visible to others. The second variable is the type of decision-making, which can be optional, collective or authority. Thirdly, communication channels can be mass media, interpersonal. The fourth variable descries the nature of the social system – customs, networking, power structure. The last variable is involvement of change agents in the promotion of the innovation.

Diffusion of innovations (DOI) theory was developed to describe the voluntary decision of an adopter to accept a new idea based on their own view of the benefits derived from use [44]. However, DOI has long been applied to the mandatory adoption of information technology beginning in the 1990's with studies of manufacturing processes, such as production and inventory control systems, adoption of personal productivity software, such as spreadsheets and word processing and databases, and software design frameworks [45]. Studies within the domain of healthcare followed, with an even stronger emphasis on social components of adoption. The importance of social interaction among physicians has been cited as a driver for adoption for innovations like antibiotics. Physicians did not want to be viewed as resistant to innovations that were vetted by healthcare experts, and want to be able to demonstrate their knowledge to professional leaders within their community [46]. Such insights have been applied to the adoption of clinical IT applications, such as EHR systems [47].

Extensions to the theory

While the theory is based on historical communication channels, the impact of information technology and the internet on communication was a particular focus for Rogers' late-career research. An extension to DOI is the arrival of the consequences of adoption. The least studied aspect in DOI theory, Rogers stated that "the usual survey research methods may be inappropriate for investigating consequences", and noted that qualitative study was most suited to looking at consequences as part of diffusion. An adapted model was used to describe three types of consequences of EHR adoption - desirable/undesirable, direct/indirect, anticipated/unanticipated [48].

Socio-technical Systems Theory

The theory of sociotechnical systems describes the impact of the complex interactions between social systems and technology on the successful implementation of a system [49]. Technology affects behavior, and how people act affects how well a technology performs, therefore it is important to understand how they affect each other. With roots in the field of human relations, sociotechnical theory takes a broad view of technology that predates current views of systems that are composed of computers and data. Early studies of manufacturing were focused on engineering improvements for productivity as proposed by Taylor in 1947 in Scientific Management [50]. It was later perceived that other elements to consider in improving performance of a system included effectiveness and well-being, introduced in Cherns seminal paper on sociotechnical design [51].

Sociotechnical theory is based on the premise that performance of a system can be improved if the two elements are considered as interdependent, that is systems are to be designed not solely as technical solutions, but rather as a collaboration with the social structure that is the context for the technology. Clegg expanded these original principles, grouping them into three categories [52]. First, meta-principles provide a broad holistic view of systems, and clarify how the design contributes to the organization. Humans are viewed as assets within the system, and technology exists as a tool for assisting humans to reach goals, with each bringing unique characteristics to the system. Secondly, content principles that describe what to consider in the design of a system – how to allocate tasks between the human and technology components of the system. Lastly, process principles offer prescriptives for system design – the importance and politics of involving users in the design process, and the need for evaluation during the design of a system.

A phenomenon known as the IT productivity paradox describes the difficulties in measuring the success of technology improvements. While technology is clearly viewed to be beneficial to industries such as manufacturing and finance, it continues to be difficult to demonstrate evidence productivity gains. In the 1970's and 1980's as computers became the brains of business, computing capacity increased rapidly, but productivity growth fell dramatically. Measures of productivity are difficult in service industries, and especially challenging in healthcare. Productivity gains for healthcare organizations may realize gains not by digitizing paper processes, but by focusing on improving communication between teams, and providing functionality for greater convenience access and quality [53]. Recommendations include creating new measures of productivity that focus on quality and cost gains, exercising caution about ROI projections, and develop usability measures that direct improvement.

Measurements are challenged by complexity. Complexity can be described as the degree of relationship between the components of a system [55]. A theoretical lens to study the complexity of health care systems is used to provide a framework for the study of complexity within the context of healthcare systems. Greater complexity makes it more difficult to "decompose" the functionality in a way that allows it to be studied. This is compounded by the greater likelihood of non-linear behaviors. Decomposition allows for the identification of actors, the information that is transferred between actors, and the artifacts that are used to contain the information.

Within the domain of healthcare, elegant solutions from a purely technical perspective have been accompanied by unintended consequences. Healthcare organizations are composed of deeply interwoven social and technical elements, where changes in one element impacts changes in the other. Technology forces changes in the social structure, clinical roles, and work processes [54]. Researchers have recognized that complex systems, even if successfully adopted by some definitions, may not be effectively used and that "unanticipated (and sometimes contradictory) changes may result from an implementation that was technologically labeled as successful" [48,53].

Early attempts at HIT systems design consisted of a summative approach, which examined a system's impact on its users. Designers are encouraged to allow the participation of users in the design of a system, overcoming the technical approach that presumes the designer knows more about the problem than the users themselves.

Sittig proposed a model to address the design, development, use implementation and evaluation of information technology within healthcare [56]. The model's 8 dimensions include:

1. Hardware and software computing infrastructure
2. Clinical content
3. Human computer interface
4. People
5. Workflow and communication
6. Internal organizational policies procedures and culture
7. External rules regulations and pressures
8. System measurement and monitoring

The model was introduced to address the problematic implementation of HIT systems – previous models lacked the ability to capture a holistic view of HIT systems, and the relationships between the 8 dimensions. Previous models rely on a decomposition and study of individual components of a system, then integrating the results into a model in an attempt to understand how to design, implement and improve a system. Current models neglected the need for continuous measurement of aspects of the system including system availability, usage of features and functionality, achievement of patient outcomes, and the identification of unintended consequences.

Human Computer Interaction

The domain of human-computer interaction (HCI) provides tools for understanding the interaction between humans and computers. Interaction with various types of users takes place through the system's user interface [57]. HCI is concerned with the design, evaluation, and implementation of interactive computing systems and the study of major phenomena surrounding the use of the system [58]. The domain contributes techniques, methods, and guidelines for designing better and more “usable” artifacts that support interaction between human and system [59].

Usability Testing

Usability testing, an evaluation approach from the HCI domain, provides a bottom-up approach to study how users interact with a system to accomplish their goals [18]. Usability testing is a set of methods to determine whether an information system meets usability criteria for specific types of users carrying out specific tasks [60].

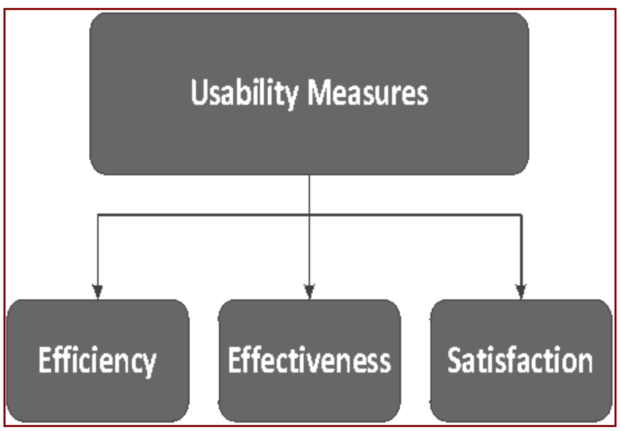


Figure 3. ISO Usability Schema (adapted from ISO-9241-11)

The International Standards Organization (ISO) definition of usability (ISO- 9241-11) , shown in Figure 3, describes the assessment of three components – efficiency, effectiveness and satisfaction. Efficiency is a measure of the resources expended by the user to complete tasks accurately and completely, effectiveness is the accuracy and completeness of specified goals in a particular context, and satisfaction represents the comfort and acceptability of the work system to its users and other people affected by its use [61].

The domain of human computer interaction defines multiple approaches to usability testing, as shown in Figure 4. A testing design can include evaluation of a real system or a representational, or mock-up system. Study participants are selected either from actual system users or can be representational users, where developers or usability experts serve as proxy for actual users in order to gain insight into user behavior [62]. Different methods include cognitive walkthroughs, heuristic evaluation, and software guidelines along with open-ended interviews and surveys [63].

Users

System		***Representational***	***Real***
	Representational	**Analytical Methods** *(Cognitive W/T, Prototyping)*	**User Reports** *(Interviews, Questionnaires)*
	Real	**Specialist Reports** *(Heuristic Eval)*	**Observational Methods** *(Experiments)*

Figure 4. Approaches to usability testing (adapted from Whitefield, 1991)

As a result of increased visibility of EHR usability issues, practical applications for usability testing were encouraged. The Usability Testing Template (UTT) was introduced in 2010 by NIST to provide a guide for vendors, health care providers and researchers to evaluate EHR systems using ISO criteria of efficient, effective and satisfying, and ultimately to facilitate usability comparisons between vendors. EHR usability has also been evaluated with criteria of usable, useful and satisfying using the TURF (Task, User, Representation and Function) framework [64]. TURF describes an EHR as usable if it is easy to learn, useful if it allows users to accomplish their work goals, and satisfying if the user likes the system and also considers it usable and useful. For the purposes of this study, we will use the ISO definition of usability.

User-centered design

User-centered design (UCD) involves users in system design to address issues of complexity and context that are not well understood by system designers [65]. UCD grew out of the perceived lack of control felt by workers in the early 1970's when information technology was introduced into the work environment [66]. As a response to the limitations of traditional requirements gathering, UCD engages users to bring their work-domain knowledge to a collaborative design effort [67]. The approach allows both users and designers to work together to define solutions that fit the user's model of tasks and outcomes.

Mixed Methods Research

Mixed methods research combines qualitative and quantitative analyses to overcome limitations that might reside with either method alone. Taken separately, qualitative approaches are good for "what" and "why" questions and include observational narratives, phenomenology, ethnography, grounded theory and case study [68]. Procedures include observations, interviews, focus groups, written, audio, or visual documents. Qualitative research is especially appropriate to generate insight, address paradigms and social phenomena, or to discover variables and develop theories. Traditional quantitative models for research are structured approaches to answer "how" questions. Methods include surveys and experiments, to answer research questions that identify variables that influence outcomes or test an established theory.

In contrast, a mixed methods design can answer research questions that are exploratory, expanding the scope and allowing for new insight and a fresh perspective on complex problems. The approach was used to study issues in education in the 1990's, which were characterized by political, organizational and interpersonal complexity. Mixed method designs were seen to provide an elegant solution for the complexity of evaluating the success of educational programs [69]. Analysis provided corroboration (convergence), elaboration – rich detail, initiation, areas for further study, and sometimes contributed to a revised research question [70]. In particular, the integration of qualitative and quantitative data in the analysis, interpretation and reporting phases of an evaluation provided opportunity for additional insight [71]. Different strategies can be used for this purpose, including data transformation, typology development, extreme case analysis and data consolidation/merging. The integration of data allows for the possible identification of new variables for study.

Mixed methods designs

The design of a mixed methods study, as are all scientific studies, is determined by the research question. Four types of designs for mixed methods have been defined – the convergent parallel, explanatory or exploratory sequential, and the embedded design [68-72]. A convergent mixed methods design allows the combination of qualitative and quantitative study allows data to be collected simultaneously and integrated in the analysis and interpretation of the results of the study. Sequential mixed methods allows the study to begin with a qualitative technique, such as a focus group, to explore an area of interest, and use the resulting themes to provide structure for a more quantitative study. Embedded designs allow the collection of additional data before, during or after major data collection to support the overall study design.

In the convergent design, shown in Figure 5, the researcher has decided that there is equal importance in collecting both types of data during the field visit. The complementary approach allows for comparison and contrast of statistical results with rich descriptive data collected during an experiment. In Step 1, the collection and analysis of one type of data is not dependent on the other, even though they are collected at the same time. In Step 2, the researcher uses qualitative and quantitative techniques as appropriate to summarize and characterize the data. In Step 3, the researcher determines how to merge the results, and how they relate to each other, to respond to the overall research question [72].

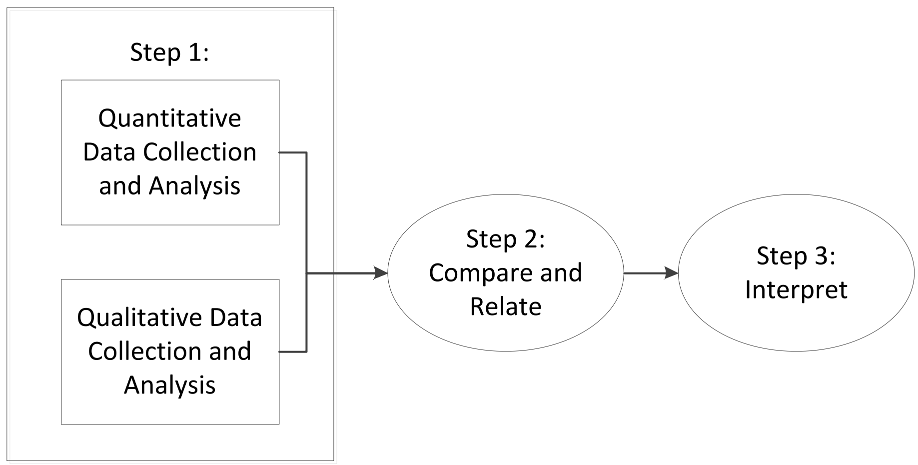


Figure 5. Convergent Parallel Mixed Methods (CPMM) Research Design (adapted from Creswell, 2010)

Grounded theory

Grounded theory is a qualitative study method based on the traditions of interactionism and pragmatism, introduced in the mid 1950's by social scientists at the University of Chicago [73]. Interactionism describes human behavior based on the interpretation of another's action within a social context, rather than the action itself, and highlights the importance of the subject in the creation of social reality. The philosophy of pragmatism states that knowledge is created through the action and interactions of humans, and that a solution to a problem is arrived at by reflective thinking. Experiences can only be understood within the larger context of society and social groups and are described as a sequence of actions and corresponding interactions.

Research questions for a grounded theory study take the form of "How does that happen?" or "What is the process that takes place in this experience – from interaction to consequence?" Research participants are selected from individuals who have had personal experience with the activity described by the research question, and often includes thought leaders who have been identified by the social group. Participants may suggest additional participants during the process of the study.

Data is collected using interviews with open-ended questions, like "Tell me about your experience the last time you saw a patient in clinic" and "I want to hear it in your own words - what is that like". During the analysis, the researcher will assemble the data into concepts or themes, to develop a rich description of the activity, or to construct a theory that describes how actions and interactions describe the relationship between components of the system. "Data collection is often based on interviews and focus groups. Corbin states that the most valuable and dense interviews are mostly unstructured – the questions are open-ended and are a freely flowing interchange between the researcher and interviewee. Observations are also used. Concepts drive both data collection and analysis.

Data analysis consists of identifying concepts or themes from the textual and narrative data. The results of the analysis may be thick description, or a theory – " a set of well-developed categories (themes, concepts) that are systematically interrelated through statements of relationship to for a theoretical framework that describes a phenomenon" [74]. Theoretical sampling is done iteratively, based on the data that is collected. When no new concepts come from the analysis, content saturation is reached and the data collection is considered complete.

Conclusion

Changes in technology and in the expectations of EHR users, including patients and providers, as well as payers and institutions, continues to shape the environment of healthcare and medical practice. A rich history of EHR adoption studies has matured to include focus on the usability of EHR systems. The current state of research indicates a further evolution to the study of how to optimize EHR systems. Optimization is the selection of a system that maximizes desired factors and minimizes those that are undesirable, while limited by a set of constraints [75-77]. For example, business owners use search engine optimization to increase the number of visitors to their website, by improving the order in which a website appears in a search generated by a user through a specific search engine, like Google. The higher the rank, the greater the opportunity that a user will actually click through to the website, overcoming constraints such as time and knowledge required for the user to select one destination over another, given a long list of alternatives. EHR optimization must begins with the discovery of factors that users deem desirable and undesirable, as well as capturing the constraints that users face in the activity of caring for patients.

The increasing complexity of the socio-technical environment of health care has challenged researchers to craft approaches that demonstrate "good science". Optimization of EHR systems requires realistic requirements for EHR functionality, acquired from groups of diverse and representative users. Components for a robust toolkit for data collection in a complex environment can be assembled using human computer interaction best practices along research methods that combine the best of qualitative and quantitative methods. A series of studies demonstrates the evolution toward EHR optimization in the following chapters.

Chapter 3 – Adoption of Electronic Health Records: A Qualitative Study of Academic and Private Physicians and Health Administrators

Introduction

Despite the potential advantages of the Electronic Health Record (EHR) [78-82], adoption of technology has been slower in health care than in other sectors of industry. Currently, the use of an EHR in ambulatory settings ranges from 42 – 90% in the United Kingdom, Western Europe, and Eurasia, with North American usage at less than 30%. However, within hospitals, adoption rates among these same nations are less than 10%. A comprehensive EHR, linking inpatient and outpatient data, exists in less than 20% of hospitals in the United States [83]. Efforts to stimulate the active pursuit of Health Information Technology (HIT) were supported by President George W. Bush, and with increased vigor by the current Obama administration [84,85]. The American Recovery and Reinvestment Act, signed by President Obama in 2009 to provide economic stimulus, encourages the development of HIT systems that provide "meaningful use". Criteria are defined in the Health Information Technology for Economic and Clinical Health (HITECH) Act and include quality, safety, and efficiency improvements. Adoption of an EHR that satisfies these criteria will be rewarded by financial incentives [86]. This initiative will require institutional transformations in culture regarding adoption of technology and the management of change.

Physician resistance has often been cited for this delay [47]. Academic physicians are expected to be less likely to resist adoption than private physicians because they are less impacted by the cost of technology and the work of data entry. Private physicians bear the cost of hardware, software and maintenance, interfaces and education for their private practices [87]. In addition, they must share information between disparate practices. Therefore, we speculate that a difference in perceptions toward EHR systems may exist between academic and private physicians, which could best be examined in an institution that involves both groups. We also included administrators, who are often involved in decisions on technology purchases.

Rogers has provided foundational work to address the problem of adoption of technology in various domains [43]. Moore further expands the discussion by describing the chasm between the initial proponents of a technology (the innovators and the early adopters), and the early majority – the group that succeeds in igniting the momentum of adoption [88]. This model is often used to describe EHR adoption, with physicians being the point of resistance.

Lorenzi presents strategies for overcoming adoption barriers which span organizational and domain boundaries and identifies categories of issues which include design, management, organization, and assessment. The successful adoption requires an understanding of EHR users and their work setting [26,89-91].

Our study was conducted at The Nebraska Medical Center, an independent, not-for-profit, 689 bed private hospital with 412 academic physicians and 581 private physicians. This unique institutional culture allows us to investigate whether potential causes for the low adoption rate are due to the differences between academic and private physicians. Institutional culture is also shaped by the decisions of administrators, who expect that the integration of an EHR into medical practice will lead to benefits including increased patient safety and prevention of medical errors [12,92-94]. The consideration of both physicians and administrators as direct stakeholders, and their alignment, is necessary to explore the keys to successful adoption and use of technology.

Methods

This research was part of an Integrated Advanced Information Management Systems (IAIMS) supported study. The research objective was to explore how private and academic physicians differ in their perception and adoption of technology within the hospital setting. More specifically, the aims are (1) to document EHR interactions that impact adoption, (2) compare these characteristics between the physician groups, (3) determine how administrators determine EHR value, and (4) to compare the views of physicians and administrators.

A qualitative approach was used to collect and analyze data using grounded theory [74,95]. This method was selected to allow better understanding of the social phenomena related to physician perceptions leading to the adoption of technology. This approach allows for collection of a rich contextual narrative that provides meaningful insight into the potential variables that impact on behavior.

Participant Profile

A convenience sample of academic and private physician and administrators was obtained based on recommendations of the study's steering committee. The steering committee was assembled to oversee the IAIMS grant and represents thought leaders from across the institution. Selection of the sample was based on users who were considered thought leaders, and representative of early majority adopters, who are more pragmatic in their emphasis on solutions rather than on technology.

The study sample of 74 was divided into four stakeholder categories and included 38 academic practitioners (AP), 14 private practitioners (PP), 12 university administrators (UA) and 10 hospital administrators (HA).

Focus Group Design

The design and timeline for the focus group sessions is depicted in Figure 6.

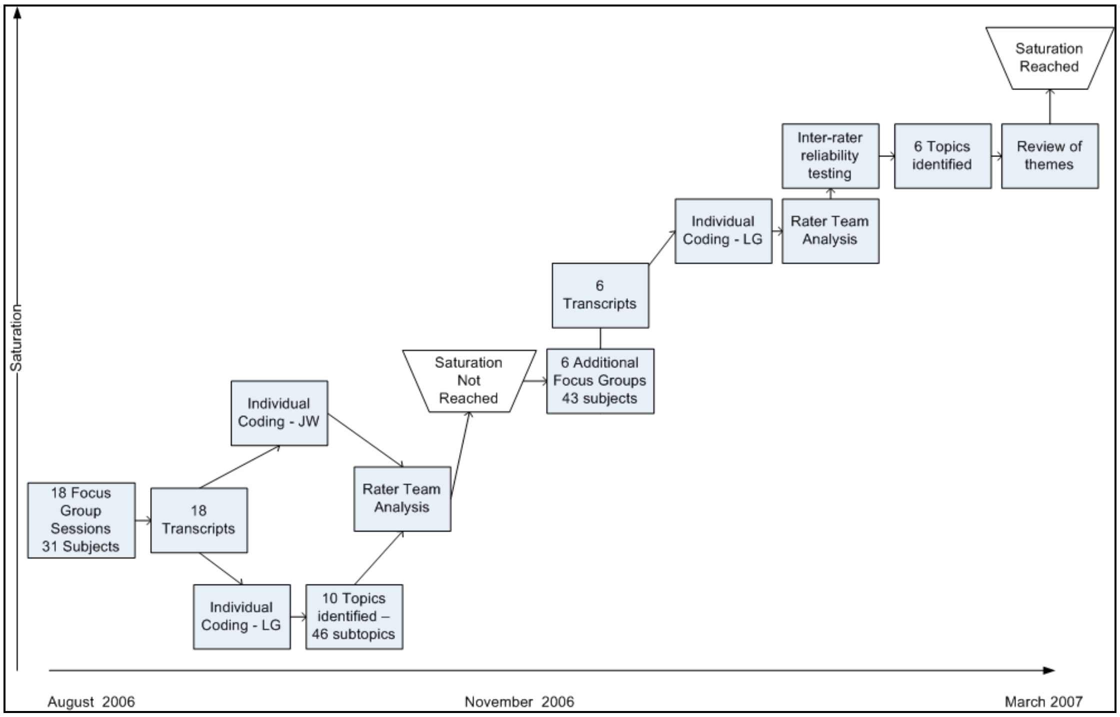


Figure 6. Research timeline and methodology

Twenty-four sessions were conducted with physicians and administrators associated with either the University of Nebraska Medical Center (academic practice) or its affiliated private hospital, The Nebraska Medical Center (private practice). All physicians used the same comprehensive EHR (GE CareCast 5.1.7) while caring for patients at TNMC. Most physicians included in the study, whether academic or private, work in different healthcare systems that use different EHR's.

Participants were asked open-ended questions related to their use and expectations for an EHR system. Questions related to their perceptions and attitudes regarding patient care, physician workflow, care team interactions, flow of health information, outcomes and clinical research, and the provider's ability to learn. Interviews and analysis took place between August, 2006 and March, 2007. An average of 7 individuals participated in each focus group which lasted 1 to 3 hours.

Group proceedings were audio-recorded and transcribed to allow coding and analysis using NVivo v7.0 software. Theoretical sampling continued until saturation was reached, and no more new ideas surfaced during the discussions [96]. At that point sub-group comparisons were performed. Two investigators independently and systematically reviewed transcripts to identify themes and sub-themes unique and similar across all groups. Themes were verified by a third investigator. Systematic coding scales included frequency (the number of times that the topic appears in the analysis), convergence (whether the topic extends across subject classification groups), and intensity (the emotion and importance of topic to the speaker) of the data elements. Using an iterative process, these themes were revised until a consensus was achieved among all three investigators. The first phase of 18 focus groups did not yield saturation, so an additional 6 sessions were added until saturation of responses was reached.

Results

The systematic review of the transcripts revealed six major themes, which include the impact of health information technology on:

- Workflow – the physical interaction of the healthcare provider with information and with patients, which includes the amount of time needed to capture, retrieve and process information.

- Patient Care – the focus of effort centering on the relationship between the provider and the patient.
- Communication – the interaction between the members of the healthcare provider team, and the methods needed to facilitate the exchange of information.
- Research/Outcomes/Billing – the use of data in a structured and summarized way to satisfy research, outcomes and billing, including capture of data in the appropriate formats.
- Education/Learning – the use of an EHR to support the provider's medical education, as well as any learning that is required to effectively use the EHR system.
- Culture – the issues related to how an EHR affects culture and the underlying beliefs and attitudes of the different groups of participants regarding use of the technology.

Themes	Subject Groupings				
	Academic Physicians (AP)	Private Physicians (PP)	University Administrators (UA	Hospital Administrators (HA)	Total
Culture	103 (21%)	61 (33%)	73 (30%)	64 (27%)	
Physician Workflow	117 (24%)	58 (31%)	35 (15%)	43 (18%)	
Outcomes and Research	69 (14%)	6 (3%)	41 (17%)	57 (24%)	
Patient Care	59 (12%)	18 (10%)	35 (15%)	41 (17%)	
Communication	66 (13%)	27 (14%)	27 (11%)	21 (9%)	
Education / Learning	77 (16%)	15 (8%)	30 (12%)	15 (6%)	
Total	491	185	241	241	1158

Table 1. Frequency of themes emerging from focus group responses

The significance of these themes is explained by the frequency of comments contained in Table 1. Themes are ranked by the number of comments coded to that theme. Although comments related to institutional culture were most frequent, it was listed at the bottom to indicate its pervasiveness in respondent comments. Further analysis resulted in the cross-case analysis documented in Table 1, which shows similarities between academic and private physicians and between university and hospital administrators. This is sharply contrasted by the differences between physicians and administrators. This indicates strong convergence between academic and private physicians on four of six themes, responding very negatively to physician workflow, patient care, communication and culture. Physician groups differed on the impact of education and learning, with academics slightly positive, and private physicians slightly negative, and their view of outcomes and research, where academic physicians were slightly positive and private physicians neutral. University (academic) and hospital (private) administrators also exhibited convergence across five of six themes, responding with neutral to positive comments, differing only on the theme of education and learning. In sharp contrast, physicians and administrators differed on nearly all themes, with the least divergent themes of outcomes and research and education and learning. Detailed descriptions follow.

Physician Workflow

Both academic and private physician groups contributed frequent comments on the theme of physician workflow, indicating convergence in this area between the physician groups. The physicians concurred with negative perceptions on workflow. They cited loss of efficiency produced by the use of technology - more time needed for data entry, less time spent with patient interaction, frequent logins, and tedious standardized forms that compromised the richness of language and depersonalized the relationship with the patient. Their emotional use of language and tone of voice indicated the intensity of their reaction.

> *"If you listen to how we describe, at least for us, the way that we do our life, this is gonna be a lot more work, uh, to do it this way and for the benefit of the organization." (AP)*

> *"So instead of being able to get all the information on the computer or all the information from the chart, you have to go to two sources to get the information that I used to be able to look at a sheet [of paper] for 20 seconds and there's just not enough access in the locations that we need to get the information." (AP)*

> *"I wrote down all of my orders just like I did, got a little crib sheet and spent time going through it. It wasn't faster… I'm still doing it, but it's, ought to be able to slide through and just grab what I need and go, "Click, click, click, click". (PP)*

In contrast, administrators made fewer comments regarding workflow, and were positive about the potential benefits of the collection of data by physicians, with few comments indicating the negative impact to workflow as articulated by physicians.

"I see, there's lots of different products out here but there's a big distinction in my mind of electronic health record and what we're trying to build here is the electronic medical record which is you know, captures a lot of the information but also is useful in the, you know, care setting and delivering that care." (HA)

Patient Care

Comments on the impact of information technology on patient care occurred with similar frequency across all four groups, identifying convergence of this important theme to both physician and administrator groups. However physicians responded intensely and often negatively, citing gaps between EHR system features and physician needs.

*"… every single thing is in there electronically, you have to wade through just a ton of administrative c**p and follow on quality reports from physical therapy you know, you're just trying to find what the ID docs [recommend] that you should do for the antibiotics—" (AP)*

"Whatever it would take to get that to be the standard of care but as every physician walking into a patient encounter walks in with electronic health record would be a huge improvement in care." (AP)

"And so the quality improvement issues are really, I mean right now we're focusing in on precision, we have a lot of people from outside the industry who don't understand they're dealing with biological organisms so they come in and want to affect us with manufacturing thoughts." (AP)

"I've had patients come to me and ask for referrals to other physicians because they feel that all he does is to look at the computer now when they're in there." (PP)

Administrators were neutral to mildly positive. They were optimistic about improved outcomes for better patient care, trends for patient ownership of health data, the movement toward patient-centric care, and the need to systematically support the continuity of care.

"One of the outcomes in going forward will be that we will be able to measure some things, improvement with care that today we can't because there is really no way to measure it. " (HA)

"I don't think we have the knack yet of realizing that the patient is still the center of focus and a lot of people spend too much time away at the electronic medical record." (HA)

Communication

Care team interactions were cited frequently by all groups, but were perceived negatively for both physician groups who noted the reduced effectiveness of communication – unclear transfer of patient responsibility, and fewer checks and balances, while administrators supported a more neutral view.

"We should force the technology to work with us. And if our intention is to have team-based rounds with nurses and physicians and other providers all communicating among one another, then we need to be sure that happens." (AP)

"… perhaps the lesson we can learn from the VA is don't build a lot of closets and stick computers in them where people could go inside and shut the door and hide." (AP)

"I think there is potential for uh, big problems with the physicians not interacting enough with nurses. ... And I think there is risk here for uh, sterilizing or dividing the relationship between the physician and the nurses." (PP)

Research and Outcomes

The impact of HIT on research and outcomes was more frequently commented on by academic physicians, who noted the potential to improve outcomes and research by overcoming cumbersome data entry and standardization of redundant data elements.

"… Show me that it helps me care for patients better. I mean, even if it takes more time, I'll do it if it helps me care for my patients better." (AP)

University and hospital administrators were neutral to positive in their responses.

However, their comments were focused on the potential of improved compliance and billing, better control of costs and data for decision-making, rather than established benefits. They also cited needed improvements of data interfaces and data collection.

Education and Learning

The topic of learning was interpreted very differently by the two groups of physicians studied. Academic physicians viewed the question from a teacher's perspective - as medical education. Private physicians viewed it from a learner's perspective - learning about how to use the technology. Not surprisingly, learning was most frequently commented upon by academic physicians who were optimistic about improved learning at the point-of-care, supporting the ongoing educational needs of physicians. However, the academic physicians were also cautious about relying too much on technology.

"Technology is not a substitute for the creativity required for the art of medicine . . . fuzzy logic, complex thinking". (AP)

"The value of learning through experience can't be overridden by technology". (AP)

Private physicians made negative comments on learning, but referred specifically to system training, citing the steep learning curve and long hours required prior to use of new EHR applications.

Culture

A significant discrepancy exists in the perception of EHR impact on the institutional culture between physician and administrators. There were frequent comments by each group, but the intensity was different – academic physicians were negative, private physicians even more so – citing limited vision for EHR's and insufficient support for current EHR projects, unclear data ownership, the existence of data silos, hierarchical decision making and the influence of external agencies and mandates, and fear that the data would be used against them.

University administrators were weakly positive, while the hospital administrators were consistently positive about improved throughput linking laboratory and diagnostics, improved compliance and billing, better control of costs, improved outcomes, the trend for patient ownership of data, the movement toward patient-centric care, the influence of national trends and national initiatives aimed at improving patient care and safety. However, they also realized the current problems caused by the proliferation of data silos.

> *"Well I think doctors are accustomed to having things shoved down their throat. By … the government, the hospitals, third party payers…" (PP)*

> *"But I would hope that it would be physician-driven, a physician effort and then people could buy into it and think it was a good idea for physicians and for patient care. And it wasn't shoved down anybody's throat…" (AP)*

> *"We have a jigsaw puzzle… And we know in the end what the picture should look like, but we can't put the pieces together." (HA)*

Discussion

The six themes that were identified were further defined by their relationships. Surprisingly, we found that academic and private physicians have a high level of agreement (frequency, intensity and convergence) on the triad of patient care, workflow and communication. They both expressed concerns about the creation of data, which is reflected in these themes. Their reactions were mixed on the topics of outcomes and research and education and learning.

> *"It's like Christians, you could be Methodist, you could be Lutheran, whatever. And 95% of doctors are the same, it's the other 5% we're gonna fight over." (PP)*

The relationship of physician workflow and communication on patient care was strongly articulated by physicians, while outcomes and research and education and learning were also perceived as impacting on patient care. These themes are shown in Figure 7. The overlap of culture with other themes indicates the pervasiveness and impact of institutional culture.

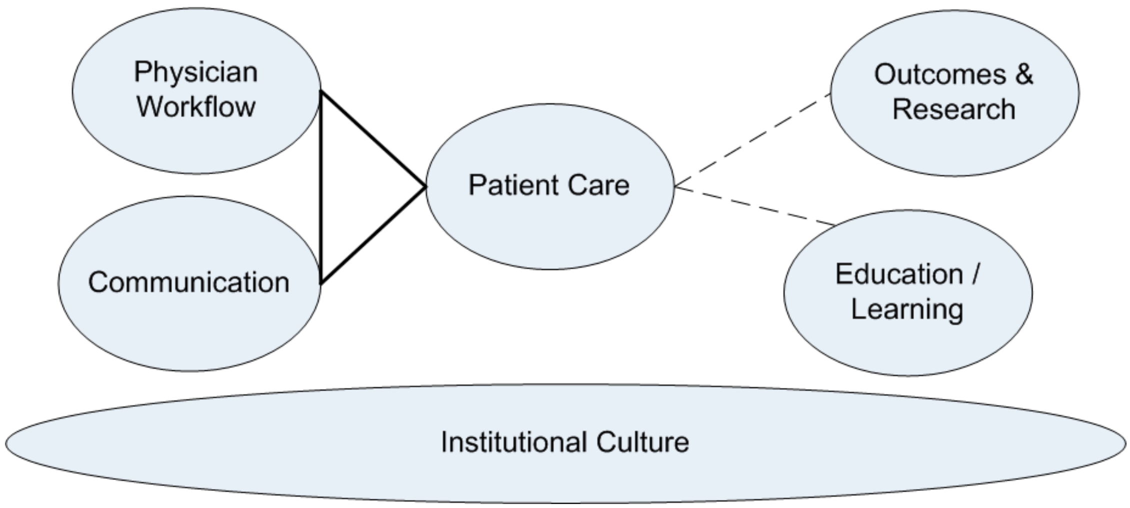


Figure 7. Six Adoption Themes Defined

A number of important studies by Ash and others [48,97-101] identify previously overlooked components to lagging adoption - the unanticipated consequences of deploying EHR systems with limited design input from providers. Unintended consequences can be grouped into two categories. The first category, consequences related to entering and retrieving information, include system interfaces that don't tolerate workflow interruptions, allow orders to be entered for the wrong patient, or require complex structured data entry between multiple screens. The second group, those consequences associated with communication and coordination, include breakdowns in the management of responsibilities and tasks related to validation of treatment and transfer of patient responsibility, and the emergence of workarounds. The study base for much of this research looks at custom-developed systems that reside within the structure of the institution. These systems may provide satisfied users, but this approach limits the availability of such costly solutions to large, funded academic institutions [102,103].

Issues of misaligned incentives, slow standards adoption, and the identification of essential product features were identified by Middleton as early as 2004 [104,105]. Our study indicates that, despite our presumption of differences, both academic and private physicians believe in the potential benefits of an EHR system, yet differ in how they articulate the costs and benefits. Discussions of cost centered on time needed to learn and use features that changed workflow and limited time with the patient. The results of our study indicate that both private and academic physicians were surprisingly similar in their need for features that maintain and enhance the relationship with the patient.

In summary, academic and private physicians both express serious concerns about the impact of an EHR on patient care, physician workflow, team communications, and culture. Academic physicians were optimistic about HIT data for outcomes and research and education and learning. Private physicians were less compelled by outcomes and research. In addition, they expressed concern about the effort required to learn and adapt to new systems. Physicians were joined in their belief that technology was being forced upon them and they are expected to adapt to technology. Administrators also showed a high level of similarity between university and hospital, similarly positive on workflow, patient care, communication, outcomes and research and their neutrality to culture. University administrators were optimistic about EHR impact on education and learning. Administrators simply believed that adoption of an EHR is necessary and will improve patient care.

An important divergence between groups may be explained by the difference between the creation of data and the use of data. The administrators' view is that the organizational use of data justifies the creation of data. They believe that creation of administrative data is the primary job of the EHR, and eagerly anticipate the availability of the data for quality and outcome measurements. In contrast, the physician's view is that data creation drives data usage. They feel that technology has been pushed on them at the expense of their efficiency, teamwork, and their time spent with the patient. Further, they are concerned that data creation drives a desire by administrators for greater data usage. Physicians believe that EHR's are inevitable, but desire a system that facilitates, not hinders, their ability to manage patients. Today, private and academic physicians believe that EHR is a solution for administrators, and that the benefits of better EHR data are far beyond their reach.

Study Limitations

This study was performed at a single medical center with a single EHR, which may limit generalization. However, nearly all physicians included in the study used different EHR's at different health systems and no differences in responses was detected. Years of experience has been proposed as a potential modifier [106], but we did not record the subjects' age or years of experience in this study. While relationships between themes were identified, more investigation is needed to clearly define the causal relationships between physician workflow, communication, and patient care. Culture was defined as a theme that provided an underlying foundation for other themes, but the nature of that relationship also requires more study, and may identify the values that underlie the responses and reactions of the stakeholders.

The view of physician adoption as a complex social phenomenon allows for discovery of the experiences, beliefs and values that hinder or encourage adoption. The resulting model provides a foundation for further study that includes the rich description of a technical system that is inseparable from its surrounding cultural system. Continued research is needed to better understand and resolve the trade-offs among competing values among the multiple stakeholders, which include both physicians and administrators.

Conclusion

An aggressive ten-year goal of universal EHR adoption by 2014 was set by President Bush. Projections imply that this goal is unlikely without incentives and product innovations. A 2010 report from the President's Council of Advisors on Science and Technology outlines financial incentives to encourage progress in the areas of information exchange that benefits patients as consumers, clinicians and researchers [107].

We contend that physician adoption of EHR systems will be driven by how well EHR's support physician workflow, communication and patient care. This is not solved by financial incentives. Rather, it is a more complex resolution of the balance of tension between adequate design and increasing requirements for data use. Specifically, the solution will include improving the usability of systems for data entry, integrating into workflow and enhancing communication. This shift drives the effort beyond remedies for physician resistance to an intense focus on the design of elegant systems that match physician requirements and exceed the limits of current expectations. Success is dependent on technology that is designed to fit the needs of physician, with a unifying goal to improve patient care.

Clinical Relevance Statement

Our study demonstrates that resistance to adoption is related to insufficient functionality and its potential negative impact on patient care. Integration of data collection into clinical workflows must consider the unexpected costs of data acquisition. This study will help aid in the design and implementation of future clinical health information technology, and outlines the different concerns of stakeholders which include both private and academic practitioners and administrators.

Acknowledgments

This project was funded by a grant from the National Library of Medicine, grant number 5 G08 LM008271-02, titled “Advancing Academic and Community Practices through IAIMS.”

Chapter 4 - Physician Super-Users, Electronic Health Records and Patient Care

Introduction

President Obama and former President Bush have called for the complete implementation of electronic health record systems across the United States by 2020 [84,108]. National organizations including the Joint Commission for Accreditation of Hospital Organizations and the Leapfrog Group, along with federal agencies such as the Centers for Medicare & Medicaid Services, have advocated for the early adoption of health information technology as a way to improve patient care. The EHR is viewed as the solution to many challenges that exist in our health care system. It is promoted for its promise to improve health care quality, prevent unnecessary variations in care, and reduce medical errors [80,109-112].

Despite this, adoption of health information technology has moved slowly since the introduction of technology to the international healthcare industry in the 1980's. In the United States, adoption rates range from 12-24%, dependent on size of practice. [47,113]. Physician resistance to technology is often cited as a cause [24,47,114,115]. Reasons for this resistance include lack of time for documentation, lack of knowledge about the system, privacy concerns, lack of standardization between systems, and the costs to deploy a technology solution [21,116,117].

In our previous study of academic and private physicians, we learned that resistance from both physician groups was related to the perceived impact of technology on communication, workflow, and patient care [118]. The selection of a broad sample of physician leaders and decision makers included a segment of older and less technically savvy users, who may not represent the segment of physicians most likely to adopt, use and improve EHR systems.

The objective of this research is to explore the perceptions of technically-savvy physicians of the impact of an EHR on patient care, where knowledge and adoption were not barriers to EHR use. More specifically, the aims are (1) to document EHR interactions that impact acceptance, (2) to describe functionality areas that affect patient care, and (3) to compare the characteristics of the two EHR systems studied. The physicians in the study practice at two institutions with long-standing comprehensive EHR's, the Veteran's Administration Nebraska-Western Iowa Health Care System (VAHC), and The Nebraska Medical Center (TNMC).

In this qualitative study, we examine whether a gap exists between physician super-users who are well versed in EHR use and health information technology, and our original study sample. Super-users are technically adept users who are trained to provide support to other users and serve as product champions, leading the way in their organization for technology change [119]. Super-users may play a significant role in successful technology adoption by providing insight into daily tasks and workflow, and providing support to other users during system implementation [43,87,120]. We explore the perceptions and insights from physician super-users who practice at TNMC as well as the VAHC in Omaha. This research extends the previous study by seeking to eliminate a potential bias against EHR use by practitioners who are technology neophytes and are resistant to change. Our sample includes recognized super-users of the EHR who have practiced only in facilities with an established comprehensive EHR.

Methods

The research objective was to understand the use of health information technology by technically adept physicians, and to compare their experiences with two well-known and comprehensive EHR systems. A qualitative design was chosen to allow meaningful insight into the potential variables and social interactions that impact the acceptance of EHR systems. Grounded theory guides both the collection and analysis of data to identify underlying concepts that describe the experience of a social group and the meanings associated with a phenomenon of study [74,95,121]. The qualitative method used in this study facilitates an understanding of physicians' adoption of technology by exploring their perceptions of EHR system interaction. This approach allows for collection of a rich contextual narrative to provide meaningful insight into the user's experiences, beliefs and values, and how these factors influence adoption.

The Veterans Administration has been a leader in the development and adoption of a robust EHR, and has received attention for its well-developed and comprehensive EHR system beginning with the development of VistA in the mid 1980's [122,123]. The system was later enhanced with the introduction of a user interface, the Computerized Patient Records System (CPRS). This comprehensive EHR contains components that include inpatient and outpatient documentation, Computerized Provider Order Entry (CPOE), alerts, medications, problem lists, image storage and retrieval, communications / routing, e-signature, progress note storage and templated notes.

TNMC is a not for profit hospital system that includes both academic and private physicians. TNMC has used GE Centricity Enterprise and its predecessors (IDX and Phamis), a commercially available comprehensive EHR, for inpatient and outpatient care for over 20 years [124]. As implemented, it has limited CPOE functionality and note templates, utilizes interfaces for external image storage and retrieval, and contains progress notes in both electronic and PDF formats.

Participants

The Chair of the Department of Medicine and Chief of General Medicine, who has published extensively on the subject of the EHR, identified a convenience sample of super-users from a comprehensive list of faculty, residents and fellows who practice at both institutions. Small group sessions were performed with a total of 20 participants, including 9 residents and 11 faculty members who accepted our invitation. The initial analysis of the first 18 participants did not yield saturation, and sessions were conducted with two additional faculty members chosen from the convenience sample. As a group the participants were sophisticated users of the EHR. They were familiar and comfortable with each medical record system, and in some cases, worked with information technology members to develop templates and forms used by the systems, advised EHR vendors on functionality, and published articles on health information technology. Additionally, several of the faculty members were experienced with other EHR systems, including Epic and Cerner.

Data Collection

Focus groups were conducted with physicians who practice at both institutions. Participants were asked open-ended questions about their interaction with EHR systems and the systems perceived benefits and limitations. The EHR systems selected for the study have been maintained and used consistently, for over 20 years at their respective institutions. Focus group sessions and analysis took place from November 2008 through December 2009. An average of 5 participants attended sessions for approximately one hour. Proceedings were digitally recorded and then transcribed. Theoretical sampling was used to identify users for additional focus group sessions as part of the concurrent data analysis until no new concepts were discovered, and saturation was achieved [74]. The resulting transcripts were reviewed for completeness and clarity prior to data analysis.

Data Analysis

Using the data analysis method of constant comparison, the two investigators independently reviewed the transcripts [95]. Concepts were found using an iterative process of reviewing transcripts following each session, identifying patterns within the participants' responses, and annotating the transcripts. NVivo v8.0 software was used to formalize the concepts and facilitate the bottom-up formulation of themes. The relevance and importance of themes was assessed using a schema of frequency, convergence and intensity. Frequency represents the number of times that the topic appears in the users' discussion, and was documented using NVivo's frequency reporting feature. Convergence, the relative occurrence of the topic across both EHR systems, was assessed by each reviewer as high, medium, or low. Intensity was defined as the emotion and importance of the topic to the speaker, using a scale of high, medium or low based on a subjective analysis of the digital recording for vocal tone, pace and volume. An example of a high intensity statement by a participant is "you actually have more interaction with the damn computer than the patient." The reviewers also noted whether the participants' perceptions were positive or negative toward the respective EHR system. The emergent themes and the rating schema were examined in an open dialogue among investigators until consensus was achieved.

Trustworthiness and credibility of the study findings were demonstrated with the following methods [125]. The investigators (an informatics researcher / practicing physician at a teaching hospital, and a researcher experienced in information technology design) independently reviewed the transcripts, and then met periodically to review their emerging themes. A third investigator (a public health researcher with qualitative study expertise) audited the identification of concepts and the formulation of themes process to ensure consistency during the collection and analysis of the data. Through an iterative process of comparative analysis [126], reviewers achieved consensus on important themes, and potential biases in interpretation were reconciled.

Results

Patient care was at the center of many of the discussions, and serves as a framework for the successes and weaknesses of the EHR. Table 2 describes the resulting themes and their relative importance to the participants, and summarizes the benefits and limitations of each EHR. Two themes emerged to describe EHR interactions that relate to patient-specific data at the point-of-care; the relationship of the EHR to physician workflow and the EHR's association with communication issues. Two additional themes described EHR interactions that were associated with aggregated EHR patient data– education, and outcomes / research. These are described in more detail below.

<table>
<tr><th>Theme</th><th>TNMC</th><th>VAHC</th></tr>
<tr><td rowspan="2">Workflow

(Frequency = 55%,
Convergence – High,
Intensity – High)</td><td colspan="2">+ Patient data available at point-of-care
- Time needed for documentation reduced time for patient care</td></tr>
<tr><td>+ Patient-centric structure, well organized

- Some patient data was scanned and not searchable</td><td>+ Patient data comprehensive and structured

- Many clicks to get to desired patient data
- Archaic commands
- “Watered down” patient progress notes</td></tr>
<tr><td rowspan="2">Communication

(Frequency = 15%,
Convergence – High,
Intensity – High)</td><td colspan="2">+ Patient data can be shared across healthcare team
+ Availability of reports based on patient data

- Less direct communication across healthcare team</td></tr>
<tr><td>+ Supports interaction with nursing</td><td>- Separation of data entry from point-of-care reduces interaction with nursing</td></tr>
<tr><td>Outcomes / Research

(Frequency = 11%,
Convergence – Low,
Intensity – Low)</td><td colspan="2">+ Potential to improve population health

- Cumbersome for individual patient management</td></tr>
<tr><td>Education

(Frequency = 4%,
Convergence – Low
Intensity – Low)</td><td colspan="2">+ Potential for evidence-based knowledge at point-of-care

- Difficult learning curve takes focus away from patient</td></tr>
</table>

Table 2. Impact of TNMC and VAHC Electronic Health Record Systems on Patient Care

Physician Workflow - Direct Influence on Patient Care

Physician workflow, as defined by the participants, is the complex physical interaction of the physician with information and with patients, which includes the amount of time needed to capture, retrieve and process information using the EHR. This theme was frequently noted for both EHR systems. Physicians spoke about the benefits of workflow, and strongly valued the accessibility of patient data when it was needed at the point-of-care, which was present in both TNMC and VAHC EHR systems. Participants also spoke strongly about the negative impact of both EHRs on physician workflow, and reinforced their concerns about the expanded overhead for documentation. A common perception was that the high cost of input and retrieval of an individual patient's information significantly reduced time available for direct patient care.

Differences were noted between the two EHR systems on issues of usability. The TNMC system was better organized but less comprehensive, with the need to access scanned documents. Participants using the TNMC EHR system spoke about the difficulties of completing documentation during a patient visit:

> *"So, we don't type in our clinic notes at this point. But we spend a lot of time outside of clinic documenting."*

> *"I just finished clinic and I now have 12 charts to dictate sometime today."*

VAHC users found the system was more comprehensive but very difficult to search. Use of templated notes at the VAHC saved documentation time and improved documentation compliance but at the expense of readability and comprehension. Participants echoed concern about documentation, and spoke directly about an interface that supported both data entry and retrieval:

> *"Follow up involving order entry takes at least 5-10 minutes per patient, so if you add that on to the end of your day – it is at least an extra hour, because nothing goes on paper, and it's not convenient to enter info until you're finished with seeing all patients."*

> *"I want it to be intuitive ... I don't want to have to ask somebody to make it for me."*

> *"You have chaplain notes, you have PT notes, you have everything and literally you're looking at a list that for one patient's hospitalization may be a list of 300 notes. "*

Communication - Direct Influence on Patient Care

Communication is the interaction between physician and patient, as well as communication within the healthcare team. Like workflow, the theme of communication was common across EHR systems, and evoked intense responses from participants. Physicians recognized benefits that included improved communication, the availability of patient data asynchronously, and the ability to share patient-centric information with other physicians, and with patients. However, direct communication between health care providers was a frequent complaint, distancing consultants from primary care providers and physicians from nurses in the inpatient environment. This was perceived as a substantially greater problem at the VAHC than TNMC. In the outpatient environment the availability of reports from other providers was viewed as a positive, however, searching through the records was still perceived as more difficult at the VA.

"[at TNMC there is] lots of interaction with nurses, they get to know who you are and often provide additional information about your patient - that happens just because of physical presence – it provides another opportunity to share relevant information that doesn't happen at the VA because there is less interaction. This collaboration also provides more reliability that orders are followed. "

"I don't think that you can rely on the medical record system to provide you all the communication that you need because any electronic system still needs to be overridden by human initiation in terms of a phone call or a page."

Outcomes / Research and Education – Indirect Influence on Patient Care

Outcomes / research is a theme that describes the use of data in a structured and summarized way to satisfy research, outcomes and billing, and includes the capture of data in the appropriate formats. Education describes the use of technology to support the physician's medical education, as well as any learning that is required to effectively use the EHR system.

Although less common, physicians perceived potential EHR benefits to improve patient outcomes and support research for populations. Yet, at the individual patient level, both systems were viewed as cumbersome and "not very helpful". In addition, the responses related to education were also mixed, but tended to be more positive. Both faculty and residents were positive about the impact of web-based educational content such as UpToDate and Google scholar. Both groups also expressed concern about the difficulty in learning how to use EHR systems.

> *"The longer you are at the VA, the more tricks you learn about using it and it becomes more and more powerful but sometimes that learning curve is very steep. "*

Summary of Themes

The comprehensive EHR systems studied had perceived strengths but also important limitations. Both TNMC's GE Centricity Enterprise System and the VAHC's CPRS system were praised for presenting patient data when it was needed at the point-of-care, addressing workflow issues of integrated access to patient data, clinical guidelines, and evidence-based domain knowledge within the space of a patient visit. The systems also were acknowledged for the potential to improve communication through the sharing of patient data among the diverse members of the healthcare team through direct access or a reporting interface. Physicians using both systems concurred on the unrealized potential for the EHR to positively impact on population health as well as to contribute to ongoing physician education through the potential delivery of evidence-based knowledge at the bedside.

While participants would not return to paper-based systems, the positive benefits of the EHR were offset by its limitations. These concerns included disruptions to patient management workflow needed to complete required documentation, elimination of face-to-face communication and feedback, as well as the potential for cumbersome data gathering for research and the potentially high learning curves for increasingly sophisticated EHR systems. Individually, the TNMC system was noted for its logical organization, but it was limited by difficult searches for patient information due to the inclusion of structured and non-structured documents. The VAHC system was applauded for its comprehensive nature, but it was considered non-intuitive and labor intensive. Neither system adequately addressed physician needs related to workflow, communication, outcomes / research, and education.

The adoption of EHR systems is influenced by how well system functionality supports the relationship between the physician and patient. The model described in Figure 8 is grounded in the findings from the study, and depicts a patient-centric rather than top-down approach to EHR adoption and usage, and defines relationships that can serve as a framework for future study. The model provides a structure to describe the relationship between desired EHR features and the satisfaction of the physician with EHR system use, which is moderated by physician commitment to the stability and improvement of patient care. The resulting framework provides an opportunity to explore each feature category. For instance, an improved workflow design, accomplished through addressing the issues of ease of documentation and the ability to share real-time patient information may improve the physicians' perception of delivery of care. The resulting user satisfaction can then be examined for its relationship to EHR adoption.

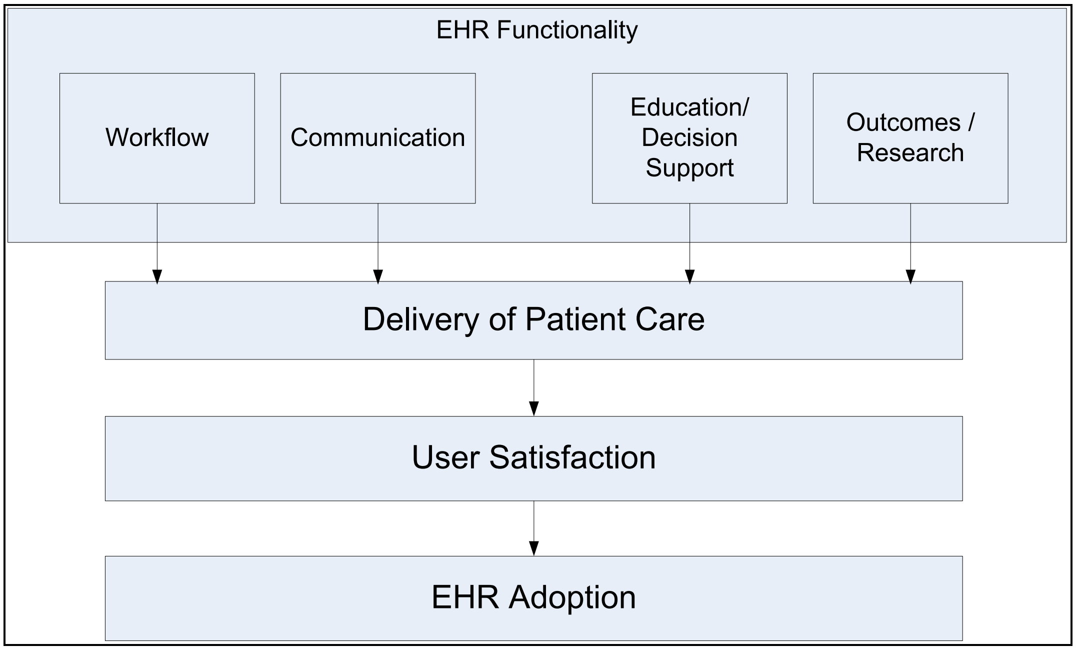


Figure 8. Drivers for EHR System Adoption and Usage

Discussion

Our study documents the gap that is present between leaders who call for the rapid implementation of health information technology and physicians (even the tech savvy) who are practicing in the trenches. Present solutions for EHR adoption emphasize financial incentives, rather than address functionality areas such as physician workflow and communication, which can improve patient care [86]. The physicians interviewed were committed to the potential of the EHR and were positive about its potential usefulness. However, their acceptance was tempered by their frustration with ease of use – particularly the impact of trade-offs between patient care and the significant time required to search for information and input data.

Our previous study, as part of an Integrated Advanced Information Management Systems (IAIMS) project, explored issues related to the broad acceptance of EHRs by health care professionals and administrators. Although the physicians in the study believed that the EHR is inevitable, surprising to us was the strong concordance of concerns raised by both private and academic practitioners about the perceived negative impact of the institution's EHR on patient care. In contrast, administrators believe that creation of administrative data is the primary job of the EHR, and eagerly anticipate the availability of the data for quality and outcome measurements. A concern of the study was that it did not include a sufficient number of young physicians in the sample, and that it examined a single EHR.

Both studies reflect similar perceptions from the participating physicians – whether they were general EHR users, or EHR super-users, particularly regarding workflow. Physicians felt that EHR applications were not designed to support their workflow, and often interrupted their interaction with patients. Although not part of our study, additional information surfaced to support the assertion that EHR use impacts negatively on direct patient care. We learned that VAHC internal medicine clinics have reduced the number of available time slots from 8 patients to 6 patients in a 4 hour clinic to compensate for the additional time spent at the computer. In addition, an internal study of workflow at TNMC indicated that house staff spent an average of 24 minutes for each inpatient. This included 20 minutes for preparation and follow-up, and only 4 minutes of direct patient care [127].

Overcoming adoption barriers requires strategies which span organizational and domain boundaries and identify categories of issues which include design, management, organization, and assessment. Successful adoption requires an understanding of EHR users and their work setting [26,89-91]. Clinical workflows are often complex, and effort is underway to better understand users and their tasks within the context of the clinical setting [128]. Many clinical systems have been commercially developed, yet research confirms issues with communication and workflow [98,129-131]. A critical piece often missing from EHR implementations is the input of the doctors, nurses and pharmacists who can identify what is needed to improve their jobs [132]. This lack of participation leads to challenges that are often found in EHR implementations in the US, and reinforces the need to enlist physicians in usability analysis and system design.

The experienced EHR users in this study call into question assumptions and strategies currently touted by US government leaders who call for the rapid implementation of technology [85]. The Office of the National Coordinator for Health Information Technology and the President's Council of Advisors on Science and Technology propose that aggressive healthcare quality and efficiency improvements be driven top-down by national initiatives. Financial incentives to encourage EHR use beginning in 2010 have been prescribed, while at the same time, policies and standards for EHR design are being formulated [107,133].

Limitations

Our findings, define relationships between themes, but do not verify causality. The rich description expands what is known about physician needs, and creates opportunity for ongoing research on antecedents for EHR usage.

Both faculty and residents were consistent in their perceptions of EHR impact on workflow, communication, and outcomes / research, therefore we did not separate the participants into groups based on years of experience. The groups differed slightly on the minor theme of education. Faculty expressed some concern about dilution of the medical education experience, yet both groups agreed on the potential benefits of the use of the EHR during medical training.

Recommendations

This study suggests EHR adoption will be stimulated by an approach which addresses user satisfaction by focusing on a patient-centric, rather than transactional, view of patient data. This includes the involvement of users in the identification of requirements that improve the effectiveness of workflow and communication, testing the usefulness and usability of interfaces, as well as the pursuit of collaborative design methodologies that combine the expertise of computer scientists, informaticists and clinicians. Current top-down efforts to spur EHR adoption, such as the Health Information Technology for Economic and Clinical Health Act (HITECH), focus on financial compensation for clinicians and hospitals. This approach overlooks both documented issues with system usability and the needs of its most sophisticated users, which may limit its success in improving EHR adoption.

Conclusion

Contrary to many observers outside the practicing community, the issues related to physician acceptance of an EHR system are not due to reluctance to adopt new technology but on real concerns about the adverse impact of EHRs on the delivery of patient care. Physicians are optimistic about EHR potential for systematic collection of data to improve patient care, but are frustrated with the cumbersome interfaces and processes of existing EHR systems.

A significantly greater effort in EHR development needs to be made to meet the needs of end-users. EHR vendors (including the VAHC) need to work with health care providers to facilitate workflow and health care team communications, and to better understand the impact of technology on patient care. The potential for EHRs to positively transform healthcare is real but not yet fully realized in current systems. Effective use of an EHR system will require more than top-down policies and incentives. It will require the input of physicians who best understand the impact of technology on patient care. Much work is yet to be done.

"…on the whole, both systems are better than the paper systems we had years ago."

Chapter 5 –Towards a Cardiology/EHR Interaction Workflow Usability Evaluation Method

Introduction

Acute chest pain accounts for approximately 5.4% of all emergency department visits in the United States [134]. In the US, nearly 6 million patients will develop heart disease and approximately 600,000 will die annually [39,41]. While over 50% of acute chest pain cases represent non-cardiac conditions, symptoms are often uncharacteristic, making it difficult to diagnose [135]. Failure to quickly and accurately determine the cause of chest pain has serious implications for cardiologists and their patients. The application of health information technology is a promising approach to more effective triage decisions; yet current electronic health record (EHR) systems often do not meet the demands for integrating complex clinical workflows [22,23,136]. In fact, it is possible that introducing additional information available through EHR systems may cause additional cognitive load for physicians [97,137].

Thus, understanding physician cognitive workflow while using EHRs and how the user interface design can support cognitive workflow is essential. One way to further understand the relationship between physician cognitive workflow and the user interface is through user interface usability evaluations. In fact, usability issues experienced by clinical providers are gaining visibility; however, EHR testing frameworks are nascent, and there are few empirical studies to document how to best approach this complex situation. Without a well-tested research method for understanding how physicians interact with the EHR system to accomplish their tasks in caring for patients, it is questionable if EHR systems will reach their potential of improving patient care.

The purpose of this paper is to present, test and analyze a usability evaluation method that is robust and yet flexible enough to understand the complexity and needs of a physicians' cognitive workflow when using an EHR system. For complex user interfaces, the user interface usability evaluation process needs to be able to be operational in a reasonable amount of time, require a practical amount of resources, and not be overly complex, yet powerful enough to handle a specialized medical team working on a complicated cardiology case. To this end, this paper presents a descriptive case study on how a cross-disciplinary research team designed a multi-faceted usability evaluation (MUE) instrument and protocol to explore the interactions between cardiologists and the EHR system user interface. In this study, the multi-faceted usability evaluation (MUE) instrument has been used at a large Midwest medical center to observe and measure how well the EHR user interface accommodates the cardiologist's workflow while caring for patients with acute chest pain.

The remainder of the paper is structured as follows: The next section presents background information on EHR workflow issues for myocardial infarctions cases, human computer interaction, usability evaluation, and cognitive walkthroughs. Section 3 discusses various clinical provider EHR interactions models. Section 4 presents our research method, design, and pilot. The paper is concludes with a discussion of lessons learned, limitations, and directions for future research.

Background information

EHR workflow issues in myocardial infarctions cases

When patients arrive at an emergency department and are having chest pains, cardiologists have less than 30 minutes to assess the situation and determine a course of action for those with myocardial infarctions. Cardiologists have to interact with a number of information systems such as electrocardiograms (EKG), pharmacy, personal health records (PHR), laboratory results, and cardiac imaging studies as well as the EHR system. Having patient information available in a format that matches the cognitive workflow of the cardiologists is a challenge, but absolutely necessary. Access to evidence-based and technology-enabled data at the point of care promises improved outcomes for patients [40]. The American College of Cardiology, a nonprofit medical society, has taken an active role in addressing the complexity of care by promoting the use of the EHR in data registries, decision support, quality improvement, and reporting [138]. Using an integrated electronic health record system has long been viewed as a way to reduce the cognitive workload; however, in many cases it may in fact increase cognitive workload and fatigue [12] [32]. The inability to reach these goals stimulated investigation by the American Medical Informatics Association's Task Force on Usability, which recommended human factors research to improve EHR usability [139]. Attention to usability for EHR system designs that support the cognitive work of clinical providers is also recognized as a requirement by the Healthcare Information and Management Systems Society [140]. Usability is defined by the International Standards Organization (ISO) as the "effectiveness, efficiency, and satisfaction with which specific users can achieve a specific set of tasks in a particular environment" [15] [61]. While the benefits of a usability-based approach to EHR requirements are well documented, the practical application of usability assessment into EHR software design and development is limited.

We propose to address this gap by focusing our study on the specific medical practice of cardiology. In this paper we present a comprehensive cognitive walkthrough approach that accommodates an interdisciplinary team of health care providers and incorporates complex cardiology scenarios that include approved patient care protocols. As an outcome of this study, we aim to validate the MUE as a robust EHR usability evaluation method to gather data and analyze user input.

Human-computer interaction

The domain of human-computer interaction (HCI) provides tools for understanding the interaction between humans and computers. Interaction with various types of users takes place through the system's user interface [57]. HCI is concerned with the design, evaluation, and implementation of interactive computing systems and the study of major phenomena surrounding the use of the system [58]. HCI contributes techniques, methods, and guidelines for designing better and more "usable" artifacts that support interaction between human and system [59].

Usability is a quality that makes systems easy to learn and easy to use which often results in reducing the cognitive workload needed to use the system. Usability includes the consistency of the interface with other systems that the user experiences, as well as consistency within the different parts of the same system. Also included is the ease with which the user can manipulate and navigate the system, the clarity of interaction, ease of reading, and the arrangement of information as well as the speed of processing information. Another component essential to usability is the visual layout of information – the density, structure, and color [60]. Information technology research has long asserted that the study of usability factors such as organization, presentation, and interactivity is key to the successful design and implementation of user interfaces [63,141]. Research suggests that usability is associated with positive effects, including reduction in the number of errors, enhanced accuracy, a more positive attitude on the part of the user toward the target system, and increased usage of the system by the user [142].

Usability Evaluation

Usability testing, an evaluation approach from the HCI domain, provides a bottom-up approach to study how users interact with a system to accomplish their goals. Usability testing is a set of methods to determine whether an information system meets usability criteria for specific types of users carrying out specific tasks [60]. The ISO definition of usability (ISO-9241-11) contains three components - efficiency is a measure of the resources expended by the user to complete tasks accurately and completely, effectiveness is the accuracy and completeness of specified goals in a particular context, and satisfaction represents the comfort and acceptability of the work system to its users and other people affected by its use [61]. There are multiple approaches to usability testing, which may include evaluation of a real system or a representational, or mock-up system, and real users or representational users, which may involve developers or usability experts [62]. EHR usability has also been evaluated with criteria of usable, useful and satisfying [64] using the TURF (Task, User, Representation and Function) framework. TURF describes an EHR as usable if it is easy to learn, useful if it allows users to accomplish their work goals, and satisfying if the user likes the system and also considers it usable and useful. TURF is a comprehensive and detailed framework that adds the study of usefulness to further explore a systems view of functionality. Other usability evaluation methods include cognitive walkthroughs, heuristic evaluation, and software guidelines along with open-ended interviews and surveys [63].

For the purposes of this study, we will use the ISO definition of usability, and focus on detailed user interactions for a limited set of tasks within the domain of cardiology. Our instrument includes measuring efficiency, effectiveness, and satisfaction. Further, we have selected the cognitive walkthrough (with modifications) approach as the usability evaluation method to study real users interacting with a real EHR system.

Cognitive Walkthrough

The cognitive walkthrough (CW) is a usability evaluation method that explores the impact of design decisions on the user's problem-solving processes and the user's ability to learn to use a system through exploration [143]. Early use of CW was summative, and occurred near the end of the design cycle, using software developers as subjects. It is now often employed as a formative tool to evaluate prototype designs with the system's intended end users, providing early feedback of unintended consequences not foreseen by the system designer. Planning of a CW includes defining the systems users, which tasks will be studied, the correct sequence of actions for each task, and how the interface will be constructed [144].

In addition, using the Think Aloud method, subjects are asked to verbally explain what they are thinking as they complete the scenario tasks using the software, allowing evaluators to understand the actions and processes experienced by the user [145]. The interaction is observed to evaluate the ease with which the user will select the correct action and complete it. An additional observer assists the moderator by recording task times, successful task completion, and other relevant information. After the walkthrough, each task is examined in sequence [60,63,146], and task times are recorded. This information is available as input to the requirements definition for system interface design.

Advantages to the use of CW over other approaches to usability testing include a better understanding of the user's goals and assumptions, the identification of unintended problems arising from interaction with the system, including increased cognitive processing and reduced workflow. The CW is a direct method which can utilize real users, real systems, and real task scenarios. Disadvantages include the relative high cost of evaluation when compared to other types of usability studies, due to the amount of time to prepare, conduct, and analyze the data. Potential bias may be introduced by task selections that do not represent the user's work leading to incomplete understanding of user's problem solving process [147]. In addition, an emphasis on low level details may underestimate the complexity of workflow for highly complex systems [148].

Theoretical Framework: Clinical User EHR Interaction Model

Electronic health record systems have been studied for over 30 years. Despite the benefits of information technology in other complex knowledge domains such as nuclear power and aerospace, progress in health information technology has been slow. Adoption has been hampered by EHR interfaces that are not integrated smoothly into clinician workflow [24-26]. While some evidence indicates that EHR systems are improving access to information, contradictory findings highlight the difficulty in assessing the progress that has been made since the introduction of EHR systems [28,29]. This gap is further documented by studies verifying the dissatisfaction of clinical providers with the additional time needed for medication and procedure ordering and patient physical and history documentation, although they believed the EHR is necessary for improved patient care [32]. This negative impact on workflow was observed even among savvy super-users, and led us to propose a framework to study the interaction between the cardiologist and the EHR system (Figure 9) [118].

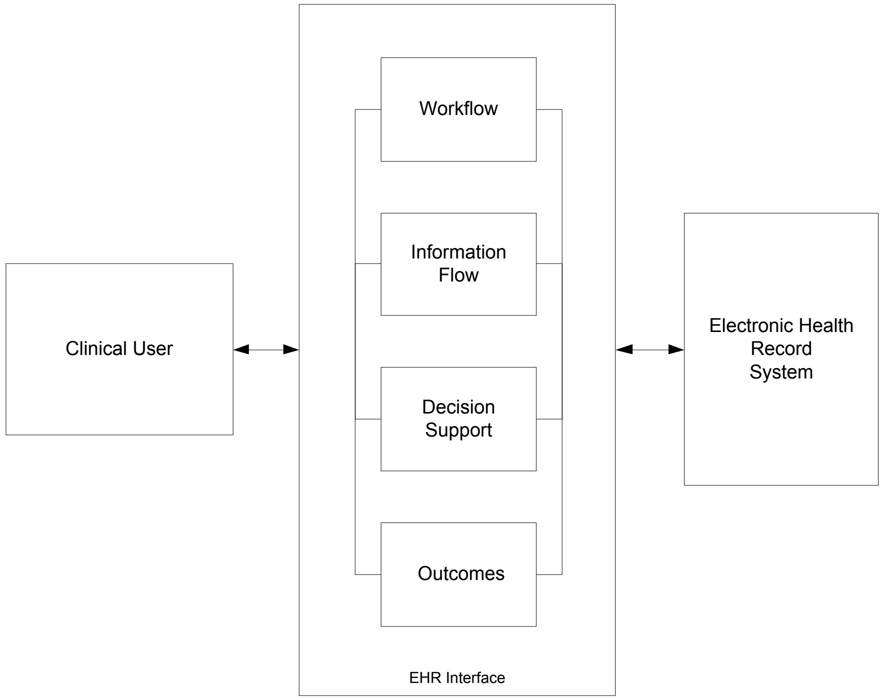


Figure 9. Clinical user EHR interaction model (adapted from [36])

Interaction between the EHR and the clinical user is grouped into four themes: workflow, information flow, decision support, and outcomes. Workflow, as defined by the study's participants, is the complex physical interaction of the clinical user with the EHR system and with information sources and destinations, to capture, retrieve, and process data. This is often expressed as the amount of time to complete an interaction. Information flow is the communication of information between clinical user and patient, as well as communication within the healthcare team. Decision support describes the use of technology to deliver guideline-based recommendations for patient care at the point of care. Outcomes is a theme that describes the use of data in a structured and summarized way to satisfy research, outcomes and billing, and includes the capture of data in the appropriate formats. The experience of interaction between clinical user and the EHR system takes place through the system's user interface. These themes are individually important for clinician acceptance of the EHR as being effective, efficient, and satisfying, and are also interdependent; therefore changes in functional capabilities in one area may have consequences in other areas. For example, the need for entry of detailed patient data to support registry data (outcomes) comes at a price of reduced workflow, because of the time required to complete documentation. Previous findings indicate that EHR system interface design is not informed by examining the clinical user's interactions, resulting in low acceptance and satisfaction with the overall EHR system, despite increasing rates of adoption [118]. The MUE framework introduced and validated in this paper was specifically designed to measure the workflow interaction shown above. We selected work flow because there is a strong void in this area and also workflow for physicians is much different than other disciplines and it is especially important in patient care in emergency situations. A natural option to study workflow is in human computer interaction domain and to measure workflow interaction effectiveness by applying usability evaluation techniques such as the CW. We discuss these topics next.

Method

The multi-faceted usability evaluation (MUE) instrument is used to study the workflow interaction between the EHR and the cardiologist using a task-based scenario for inpatient cardiac care. In this study, we discuss the design and demonstrate the use of the MUE as an instrument for EHR usability evaluation in the department of cardiology at a large Midwest medical center.

The EHR system evaluated in this study was introduced 30 years ago for mid-size to large ambulatory medical groups, hospitals, and integrated healthcare organizations. The integrated system supports administrative functions including billing, registration and scheduling; as well as clinical functions such as patient documentation, medication ordering and clinical decision support for various medical providers. It is one of the top three EHR systems in the US, and is widely used within large hospital systems.

An application specifying the selection of participants for the study, and the use of realistic patient data was submitted to the local Institutional Review Board (IRB). It was approved as an exempt study.

Multi-faceted Usability Evaluation (MUE) framework

In order to understand how well the EHR system accommodates the workflow it is important to examine all of dimensions (e.g. audio, video, data entry, and navigation), along with the contextual components of the task scenario and patient data. The MUE framework combines a portable usability lab, complex patient case scenario, and realistic patient data (Figure 10) to provide a comprehensive view of the user workflow. One of the main goals of the MUE is to be able to capture the participants' thoughts and cognitive workflow while they are using the EHR in a clinical environment. The MUE was designed by a research team consisting of physicians, information technology researchers, and healthcare informaticists. Our aim was to create a framework that addresses the complex, multi-disciplinary environment of cardiac inpatient care.

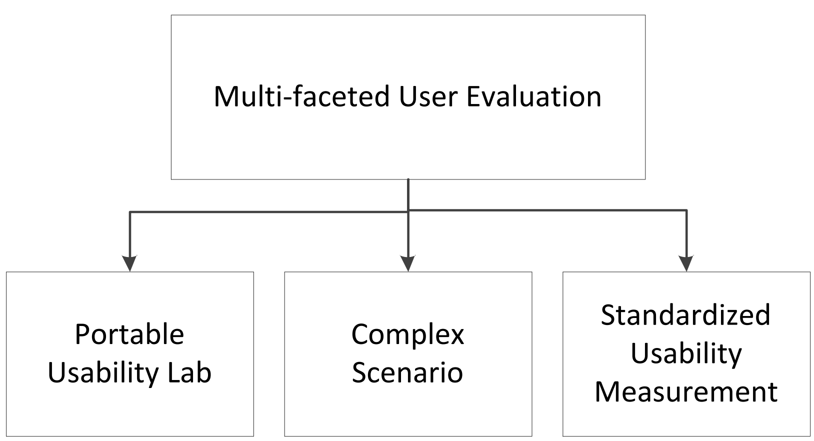


Figure 10. Multi-faceted user evaluation (MUE) instrument

Hardware Considerations

There were several important hardware requirements to take into consideration so that audio, video, data input/output, and system navigation data could be captured for further analysis. The clinical environment that we chose did not allow software to be installed on institutional computers to limit exposure of patient data to unauthorized users within the institution's network. To this end, a portable usability lab was needed.

The portable usability lab was designed to be self-contained, and connect easily to a user's clinical workstation. The lab consisted of an Epiphan Systems VI2USB™ high definition digital video capture device which was connected by a USB to the user's monitor, capturing what the user is seeing and the actions s/he took. An external omnidirectional microphone was set up next to the user's computer to record "think aloud" comments" and any additional verbalization as the user completed the scenario. The software included "Audacity", an open-source audio editor, and recorder to capture live audio and convert it to an mp3 file. Both video and audio sources were connected to a laptop PC, which provided status of active recording, as well as data storage for large audio and video data files. Use of the portable lab did not require any changes to the user's PC, and satisfied the institution's restriction on software installation. Figure 11 models the configuration of the portable usability lab.

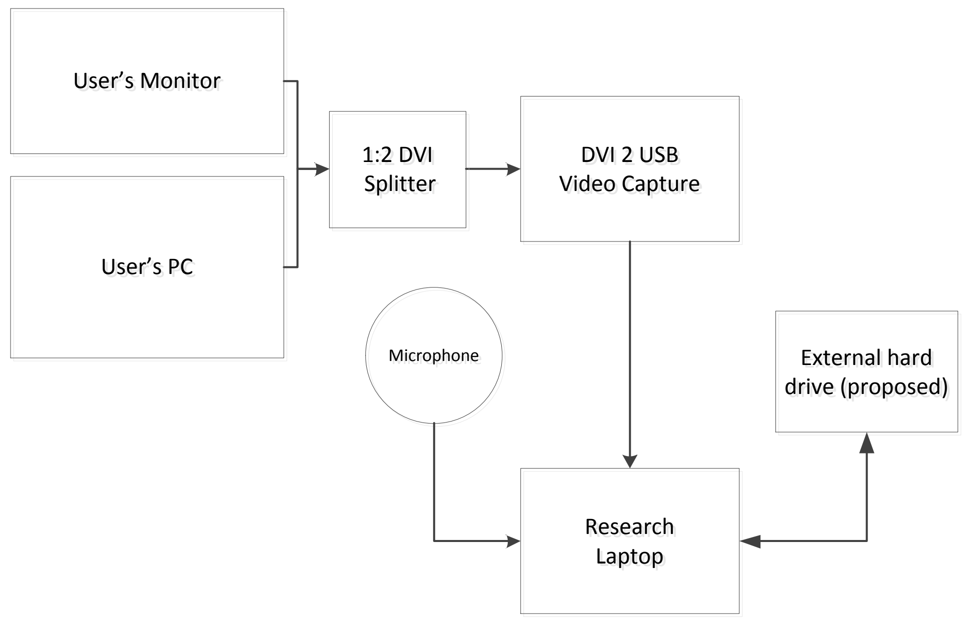


Figure 11. Portable usability lab schema

Environmental Considerations

An important consideration for EHR usability studies is the context in which the evaluation takes place. The MUE is flexible and could take place in a clinical settings also, to accurately portray the complex environment of interruptions and multi-tasking typical of EHR usage.

Context

The importance of a well-chosen and developed scenario is essential to the discovery of a user's cognitive process. A disadvantage of CW is the choice of tasks that do not accurately represent the user's workflow. For our study, we chose the standardized cardiac inpatient scenario published in the National Institute of Standards and Technology (NIST) document 7804, which provides guidelines for the technical evaluation, testing, and validation of EHR usability [149]. The scenario was designed by NIST as a realistic clinical situation for assessing of EHR usability. The scenario was approved by the cross-disciplinary research team to appropriately address the tasks performed by the cardiologist in the care of acute cardiac patients. Tasks include documentation of patient status, ordering of laboratory tests and diagnostic procedures, modification of active medications, and creation of discharge information. Figure 12 is an example of the complexity of one screen that a cardiologist views.

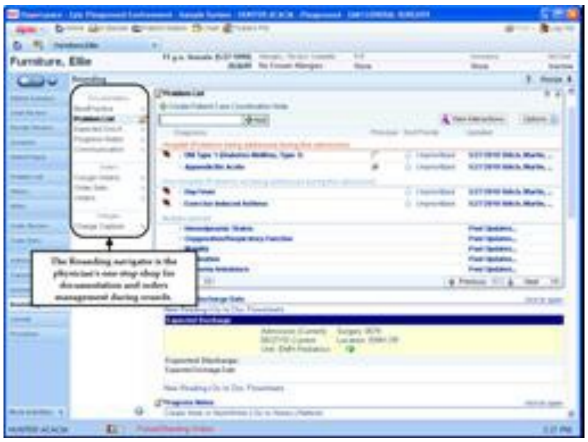


Figure 12. Sample EHR user interface

The usability evaluation protocol design

As described above, the MUE is a multi-faceted research instrument designed around the cognitive walkthrough usability evaluation method. MUE included input from a multi-disciplinary team of researchers consisting of physicians, HCI experts, and health informaticists. The team began by identifying the steps in the MUE process. The steps are listed below and flow chart showing the parallel steps of the participant and the investigators is shown in Figure 13.

1. The moderator described the purpose of the cognitive walkthrough.
2. A complex cardiac scenario was given to the participant to read.
3. The participant was instructed to complete the tasks defined in the scenario using the EHR system until all tasks were completed.
4. The assistant investigator digitally recorded the sessions, logging user's system interactions and completion times as they completed tasks. Observations, participants' comments while using the system, where and when system problems occur, and nonverbal user feedback were entered as field notes.
5. The participant was asked to complete the System Usability Survey.

6. The moderator then interviewed the participant with open-ended questions to get additional input on the user's experience.
7. After user was dismissed, a debriefing was conducted to collect additional data (possible improvements in structure of study, system set-up, etc.).

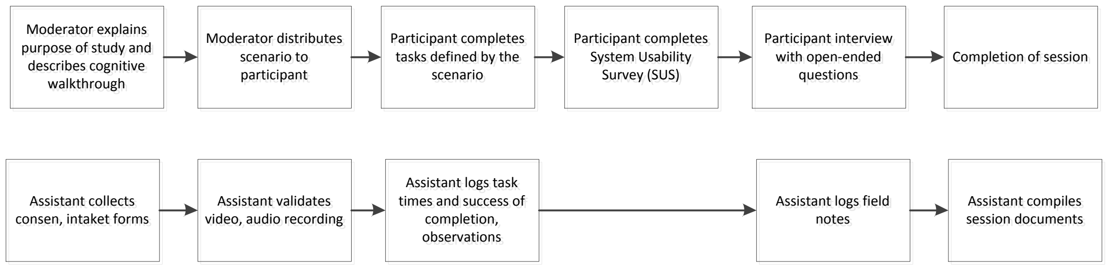


Figure 13. MUE flowchart of progress

The research team then developed an observation scorecard to record data (see Appendix A) and the System Usability Survey. Together, these artifacts captured data on the EHR effectiveness, efficiency, and satisfaction. We explain in detail how these parameters were applied.

1. Effectiveness includes task success and time to completion, and task failures – where the user abandoned the task or didn't reach the correct answer within the allotted time.
2. Efficiency is measured by variance of task time from anticipated time specified in the scenario, and any deviation from the path specified in the scenario. A post-walkthrough interview follows, where participants answer open-ended questions and discuss perceptions of usability and satisfaction [74].
3. Satisfaction is measured using an adapted System Usability Survey, a simple, short evaluation often used as a "quick and dirty" usability scale that has been modified to assess EHR usability [150]. The survey provides additional data about the user's ability to navigate the menu, the ease of finding information, as well as how satisfied they are with the system. Results from each session were captured on an observation scorecard.

Pilot

Next, the research team conducted a full-blown pilot to to test how well the portable usability lab worked using the MUE instrument. The session took place within the department of cardiology. The pilot took approximately 45 minutes. The participant, a cardiology fellow, was a frequent EHR user. The participant was comfortable with the "think aloud" request, and was reminded to speak loudly. The additional hardware of the portable usability lab was not perceived as intrusive. The EHR training system was used, and a test patient was chosen with similar characteristics to the profile of the patient described in the cardiac inpatient scenario. The participant completed the scenario, the system usability survey, and the interview. The materials were collected and the audio and video recording sessions were closed and saved on the laptop computer.

Discussion

There were several lessons were learned from our pilot. First, the portable usability lab allowed us to take the study to the participant's work environment. This is important because it is difficult to simulate all the activities, interruptions, and instrumentation that impact the physician while using an EHR. We also evaluated how well the hardware and software met our needs. The microphone selected for use in the study was sensitive enough to pick up sound from the participant's computer – not only clicks, but fan noises, which made it difficult to hear the user's voice. We will need to further investigate how to adjust the sensitivity. Although, the screen capture capability was successful, allowing nearly 40 minutes of user screen displays. Audio was accurately captured in wav files. We were especially pleased with these results as we were able to use open source code and keep the pilot costs reasonable.

Second, we carefully considered how well the NIST cardiac inpatient scenario matched the cardiologists' expectations. We were interested if the scenario provided a representative number of tasks, as well as a structure for the recording of observations and task times and completion rates. We did find that some tasks in the scenario were not relevant to the cardiologist, and did not match the user's normal workflow. This is an important finding as we will not have multiple opportunities to re-do our study with cardiologists in the field because of other demands on their time. Future plans will include development of additional and complex scenarios that match the institutional setting.

We were pleased with the observation scorecard we developed specifically for this pilot. It was especially effective because all the data was captured in one place and in an organized manner. Further it reminded the observer of all the parameters that need to be logged during the 40 minutes session.

Third, setting up a test patient data to match the profile of the NIST scenario proved to be problematic in this setting, as access to the system was limited to trained users. So the non-medical investigators were not able to make modifications. For the pilot, an existing test patient exhibiting chest pain was selected, introducing mismatches with the scenario. For instance, a task requiring modification of active medications was not relevant, since Lasix was not ordered for the test patient. In the future we will need to spend even more time creating or searching for a test patient with relevant data (demographics, vital signs, labs, medications, etc.) to match the scenario, along with a process to "reset" the patient, restoring the original data, so that we have a repeatable process. We recognized that this could be a potential problem, but we needed to move forward with the pilot to provide additional information on how we might address these problems. Further, we had all the hardware and software in place including the physician willingness to participate.

In addition, several procedural items were noted. A secondary researcher in the role of observer is essential to capture task times and completions real-time, as well as to assist with set-up and take-down and ensure that video and audio capture is successful. It may also be necessary to have an IT professional to monitor the hardware and software. The assortment of connections, cords, and adapters, along with the additional devices required technical knowledge. Future plans will include some consolidation schema to minimize set-up and take-down once the environment moves to a clinical setting.

Conclusion

The purpose of this study was to introduce and test a cardiology/EHR Interaction workflow usability evaluation process to improve the design of EHRs to better match the workflow of physicians and ultimately reduce cognitive workload. There is a high penalty when an error occurs when using an EHR and thus this is why this research is so important. In our study we demonstrated and tested the techniques that work in a clinical environment. We have designed a robust method for cognitive workload usability evaluation and have found a way to actually implement and test it in a complex cardiology environment.

The limitations of this study as one might expect is that we need to further test the MUE instrument with more subjects. The research team intends to extend MUE instrument to apply to an interdisciplinary team of participants such as nursing, emergency, and family practice. This can provide potential benefits that include standardized user interfaces required by all EHR systems based on similarities across user groups and the specification of new EHR functionality to support the variation observed among user groups.

Further, future studies will introduce new scenarios designed with domain expert team members to further study elements of workflow, information flow, decision support, and outcomes.

Chapter 6 – EHR Optimization for a Routine Cardiac Follow-up

Introduction

Study of the use of electronic health record (EHR) systems within the US has been summarized in previous chapters, accompanied by discussion of appropriate methodologies for studying EHR usability within a naturalistic clinical setting. The expectations that EHR systems will meet increasing demands for the collection and retrieval of information at the point of care are common outside the context of clinical work. Efforts to expand EHR adoption have accelerated, however the benefits have been elusive. Previous efforts to develop EHR functionality often overlooked the cognitive needs of the clinical user, resulting in dissatisfaction with current EHR systems. Fortunately, issues experienced by clinical users have gained visibility and include EHR systems that require hours of training prior to use, increased requirements for clinical documentation, and unintended consequences from EHR designs that don't match the cognitive processes of users [116,151,152]. Recommendations by industry and government experts point to a lack of focus on usability. EHR usability testing frameworks and toolkits have been proposed by the National Institute of Standards and Technology (NIST), as well as the University of Texas at Houston's TURF integrated toolkit for usability evaluation [64]. These works have provided needed foundation and momentum for usability evaluation, yet empirical studies are needed to demonstrate the impact of improved usability on clinician workflow.

Rationale for this study

User-driven recommendations for EHR design are needed to push current boundaries of EHR usability. A reliable and well-tested usability evaluation method is essential to understand the interaction between clinical users and EHR systems in caring for patients in a realistic clinical setting. The collection of data on existing EHR designs will identify gaps and produce the framework for a requirements specifications document that will match system functionality with the needs of different types of users, who each play an important, yet very different role in patient care.

Methods

Objective

It was hypothesized that substantial differences in EHR usability can be detected using a Human-Computer Interactions (HCI) framework, which includes a realistic clinical scenario, a mobile usability laboratory, and a cognitive walkthrough. The study is aimed at identifying and describing usability gaps that exist between different types of providers, at an academic institution, using a standardized usability testing protocol. We measured usability and classified user requirements for EHR functionality using a mixed methods approach.

Study Design

A convergent parallel mixed methods (CPMM) study design was combined with a robust EHR usability testing framework to allow collection and analysis of qualitative and quantitative data from a representative clinical testing environment. CPMM was used to collect and analyze qualitative and quantitative streams of data. This approach is well-suited to the study of complex research questions and allows researchers to compare statistical results with rich descriptive data collected during system interaction, providing a more complete picture of usability than a purely qualitative or quantitative study [69]. CPMM allows for development of an overall understanding of provider's perceptions of EHR usability through the collection of survey and usability data, while also collecting rich descriptive data through observation.

In step 1, quantitative data is collected and analyzed at the same time that qualitative data is captured using the same study protocol. Using this approach, both types of data can be collected during the same interaction with the participant, providing rich descriptive data and objective quantitative data from the same session with the participant. In Step 2, the two sets of results are then merged to assess how the results vary across provider roles. The process of comparing and documenting relationships between themes and evaluation scores is continued until the researchers determine that no new themes have been discovered. In Step 3, the relationships between the different types of data are examined, and findings are articulated. CPMM was chosen because it allowed both types of data to be collected during the same session, making it more cost effective than conducting separate studies. A CPMM strategy also supported the multi-disciplinary team of researchers, who had individual strengths in quantitative or qualitative research methods.

EHR Usability Evaluation Framework

A usability evaluation framework (Figure 14) was developed to test the hypothesis through the study of EHR usability in a realistic clinical setting. The framework was used to conduct standardized usability testing, and included a scenario, cognitive walkthrough, and a standardized simulated patient. A predecessor to this framework was discussed in Chapter 5. The revised framework was built to address the issues that were identified in the previous study.

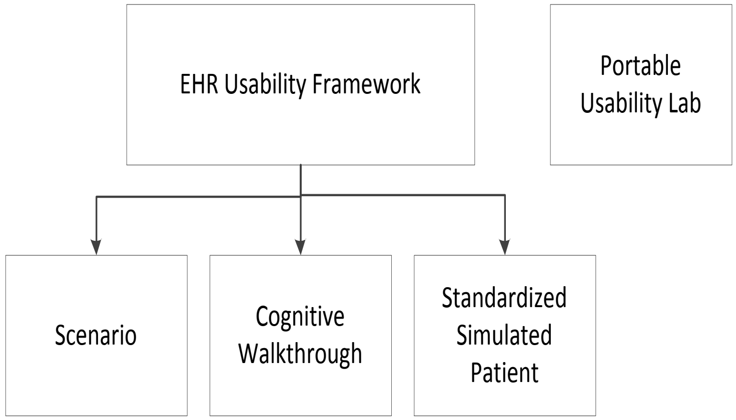


Figure 14. EHR Usability Evaluation Framework

Portable usability lab

The previous version of the portable usability lab contained many components, requiring extensive set-up time and testing to ensure connectivity. Portability, a critical requirement for realistic clinical studies, was compromised by the complexity of the many components, and the set-up procedures requiring technical support. This study used a customized Mangold International mobile usability observation lab to capture audio, screen video and keystroke/mouse data. The portable lab was identified as a vital component to overcome the artificial testing environments that limited many EHR usability studies, allowing testing in a realistic clinical setting, as discussed in Chapter 5. The purchased Mangold lab provided an integrated solution to address the limitations discussed in the previous study, specifically insufficient audio quality, unwieldy connections between the lab components, and the absence of analytical tools. Mangold’s standard lab included a workstation using VideoSyncPro, a workstation using LogSquare keyboard/video/mouse capture software, two high definition video cameras with tripods, a KVM switch and proprietary INTERACT 14 analysis software. Data was stored on the workstation, and exported as a media file to a secure server.

Scenario

An earlier version of a generic scenario for cardiac care contained tasks that did not match the provider's workflow, introducing confusion and frustration. In the current study, a team of local and national cardiology domain experts constructed a cardiac return visit scenario to include a variety of representative tasks to provide sufficient context for an assessment of EHR usability. A usability task framework (Figure 15), was constructed from findings discussed in Chapters 3 and 4, and included user-defined themes of medical decision-making, workflow, communication and patient safety. EHR users defined medical decision-making as the cognitive processing required for diagnosis, treatment decisions, drug administration and preventive interventions required for patient care. Workflow was defined by users as the complex physical interaction of providers to process information, whether with the EHR, the patient, or with other providers. Users felt strongly that workflow included the time to capture, retrieve and process information using the EHR. Patient care was defined as a patient-centered focus on healthcare management, and echoes the Institute of Medicine's mission to provide care that is respectful of and responsive to individual patient preferences, needs, and values [7]. Users defined communication as the exchange of health information between provider and patient, and between provider and members of the health care team – whether consulting partners, primary care physicians, nursing, and medical staff.

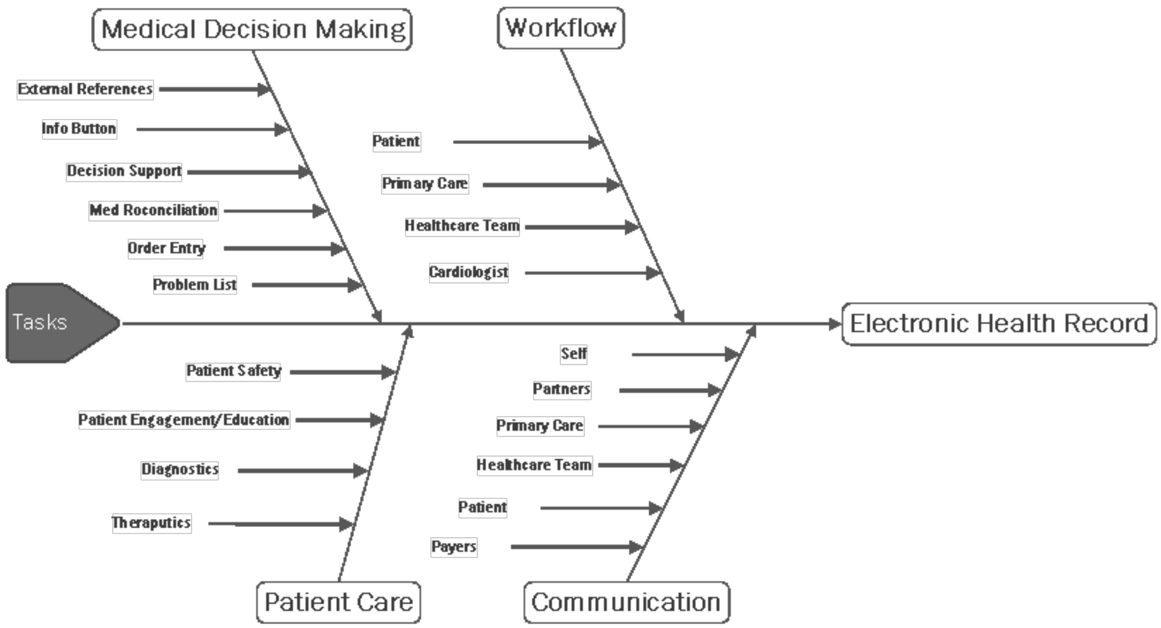


Figure 15. Usability Task Framework

The cardiac return visit scenario provided a standardized and repeatable task list for two purposes – first, to guide understanding of the specialized information needs of cardiologists and secondly, to provide a sufficient level of granularity for assessment of usability. The scenario included the tasks as shown in Table 3. Sub-tasks were further defined to include specific requirements based on American College of Cardiology (ACC) guidelines for cardiac patient care.

Task Number	Task	Sub-Task
T1	Coronary Artery Disease	Myocardial Infarction
T2		Stent present
T3		Smoking status
T4		Angina classification
T5		Medications – statin
T6		Medications – antiplatelet
T7		Medications – Beta blocker
T8		Exercise
T9		Lipid profile
T10	Heart Failure	NYHA
T11		Symptoms (dyspnea, orthopnea, exertional SOB)
T12		HF Education
T13		ICD Counselling
T14		Medications – ACB / ARB
T15		Medications – Beta blocker
T16		Ejection Fraction
T17	Atrial Fibrillation	Symptom assessment
T18		CHADS2VASC
T19		Antithrombotic therapy
T20	Hypertension	BP at target
T21		Hypertensive Medications
T22	Check medication needs	
T23	Patient education	

Task Number	Task	Sub-Task
T24	After visit summary	
T25	Level of service	
T26	Generates a note	
T27	Note to Referring physician	
T28	Uses order entry	

Table 3. Cardiology return visit scenario task hierarchy

Simulated Patient

A live standardized patient-actor was developed as part of the framework. An outline was prepared using the protocol developed for medical student training in Site A's medical simulation laboratory. The outline, included in Appendix B, provided a set of patient characteristics and scripts for the scenario that were used with all participants. An actor was selected and trained over a series of sessions until the simulated patient's medical history was familiar. A series of supporting documents were presented to the participant to provide past clinical notes, labs, and vital signs for the simulated patient to be used during the scenario (Appendix C-J).

EHR Usability Assessment Criteria

The International Standards Organization definition of usability contains 3 elements; efficiency – a measure of a user's resources needed to complete a task, effectiveness – the accuracy and completion of goals appropriate to the context, and satisfaction – the acceptability of the system to users and others impacted by use of the system [61]. This study used a combination of quantitative and qualitative measures to focus on assessment of EHR effectiveness and satisfaction. Successful task completion, the percent of tasks that are completed without error, was used as a quantitative measure of effectiveness. In addition, the System Usability Survey (SUS) was used to measure user satisfaction [150]. SUS was used in this study to evaluate the participant's baseline satisfaction with their institution's EHR system. Qualitative data was collected during the same session. User comments and non-verbal communication were noted, and observations of user behavior were collected by the moderator and observers for further analysis.

Cognitive Walkthrough

Figure 16 describes the steps of the cognitive walkthrough. Participants first filled out a consent form and an intake form at the beginning of the session. Demographics included the participant's role as fellow, faculty, or nurse practitioner, years of experience in that role, gender, frequency of computer use, and years of experience with their institution's EHR system. The moderator then described the purpose of the cognitive walkthrough and presented the scenario and the simulated patient to the participant. Participants were given general instructions to perform tasks that they would consider to be part of their normal workflow. In addition, participants were asked to "think aloud", to provide additional insight into cognitive activities needed to proceed through the scenario. At the end of each session, participants were asked to provide additional suggestions and feedback on how to improve their overall experience using the EHR. After the simulation was complete, and the participant was dismissed, the digital files were closed and stored. The moderator, simulated patient, HCI expert and cardiology domain experts each had the opportunity to contribute their observations to the field notes collected during the simulation.

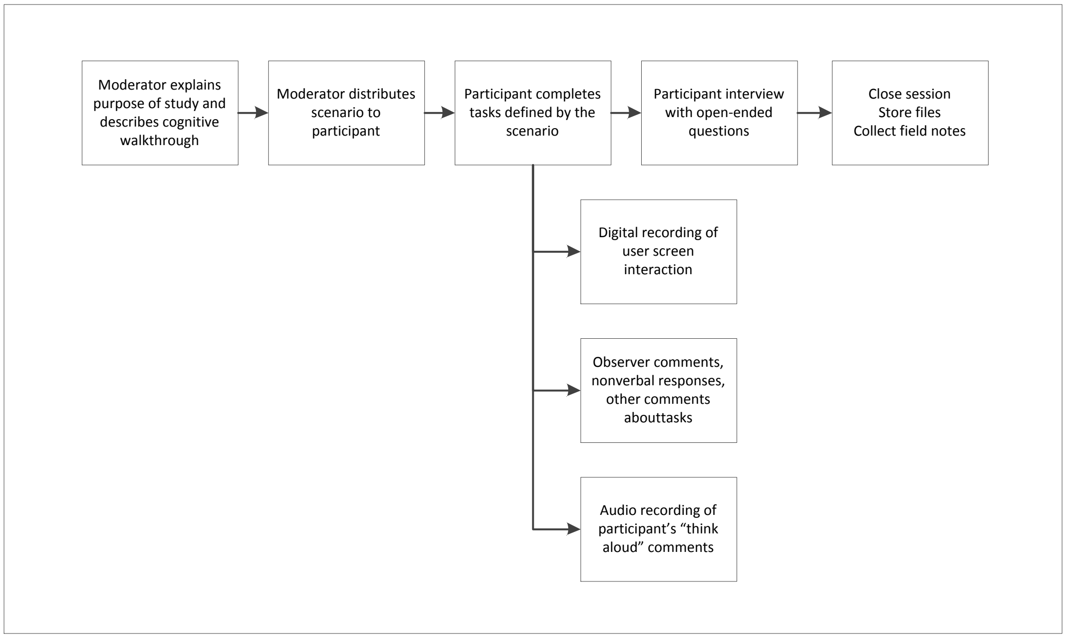


Figure 16. Cognitive walkthrough timeline

Participants

The study participants included 3 academic cardiologists (CC), 3 cardiology fellows (CF), and 1 nurse practitioner (NP) at a Midwestern academic medical center. The EHR system used by the institution is one of top 3 most widely used EHR systems in the United States at the time of writing. This project was approved by the site's Institutional Review Board as an exempt study. Participants were identified by convenience sampling, and were contacted through an introductory email and invitation to participate in an EHR usability study.

The study took place at the University of Nebraska Medical Center (UNMC), an academic medical center located in Omaha, Nebraska. UNMC works with its partner, Nebraska Medicine, an independent, not-for-profit, 678 bed private hospital with 1,100 physicians, and 10,800 employees. Sessions were conducted at the institution's Clinical Simulation Lab, which was equipped with examination rooms that closely resemble those of the actual practice environment.

Data Collection

Data was collected beginning in November 2014 through February 2015. Simulations varied in length from 26 minutes to 58 minutes. Participants were asked to complete an intake form and were then given instructions for the cognitive walkthrough, to think aloud while completing the tasks, and a reminder that the evaluation was directed toward use of the EHR system, and was not a test of the participant's performance. Participants were then provided a sheet to describe the patient, and were asked to complete the tasks that they would normally do in preparation for the patient encounter. Representative patient data was provided (labs, previous clinical notes, vital signs, patient history, medications) see Appendix. At the end of the session, participants were asked to comment on their interactions with their institution's EHR system to assess their level of satisfaction

Data Analysis

Using CPMM, the analysis of data from the simulation studies was done concurrently and iteratively. Qualitative and quantitative data were first examined separately, and then combined to observe relationships between the two streams of data.

Constant Comparison of Qualitative Data

The audio portion of the simulations was imported into NVivo 8.0, and was labeled with the participant's unique identification code. NVivo, which has been described briefly in previous chapters, is a comprehensive qualitative data analysis software program. Built upon the methodological foundations of qualitative research, NVivo allows character-based coding, rich text capabilities, multimedia data annotations, and dynamic models to capture and organize rich data [153,154].

The investigators independently reviewed each recorded simulation to identify patterns within the participants' responses, and compiled a summary of observations for each participant. The summaries were then coded in NVivo. As new simulation sessions were added, the process of coding and grouping was repeated, ensuring consistency in the process.

Using the method of grounded theory and constant comparison [95], the investigators met in a review session to compare concepts, resolve discrepancies in interpretation, clarify the various meanings of words used by the participants, and to discuss themes emerging from the analysis. Important user themes were built using this iterative process of reviewing and grouping concepts during the review sessions. Investigators assessed the relevance and importance of themes using a rating schema of frequency, convergence and intensity. Frequency was defined as the number of times that the topic appeared in the simulation sessions, and was documented using NVivo's frequency reporting feature. Convergence, the relative occurrence of the topic across the unit of analysis, in this case the provider role, was assessed by each investigator as high, medium, or low. Intensity was defined as the emotion and importance of the topic to the user, and was rated using a scale of high, medium or low based on a subjective analysis of the digital recording and/or field notes for vocal tone, pace and volume, and whether the participants' perceptions were positive or negative. According to grounded theory, the iterative process of review and data collection continued until consensus was achieved and potential biases in interpretation were reconciled.

EHR Usability Assessment Criteria

One of the investigators is a domain expert in cardiology, and performed the usability assessment. Using a score sheet containing the tasks defined by the scenario, each participant's recorded scenario was reviewed, and 28 tasks were marked as "1" for complete, "0" for incomplete. Individual participant scores were computed, and a mean score for cardiologists, cardiology fellows, and nurse practitioner was recorded. In addition, participants completed a System Usability Scale (SUS) survey to establish their level of satisfaction with their EHR system. SUS scores were normalized to a score of 0 to 100. Scores of 70 or above are considered to be acceptable, scores below indicate a system that lacks usability [150,155,156].

Results

Overall, each of the 9 participants completed the System Usability Survey and the simulation using the cardiology return visit scenario. Each provided additional comments through the post-simulation interview. All participants were comfortable in the use of their institution's EHR system, and had little difficulty understanding the tasks required by the scenario. Using the CPMM framework, qualitative and quantitative results are first discussed separately.

Qualitative results using constant comparison

The results of constant comparison and the investigators' review sessions identified the relative importance of the proposed themes, as depicted in Table 4. Overall, medical decision-making was most often commented on by participants, followed by workflow and communication, with the topic of patient care less prominent. Cardiologists voiced concern about negative impacts of EHR use on workflow and patient care. In addition, they spoke strongly about difficulties they encountered as they gathered information to make difficult decisions for patient care. Fellows and nurse practitioners were less critical about their EHR interactions, and commented more frequently about workflow and time committed to documentation.

Frequency of Theme	***Communication***	***Workflow***	***Medical Decision Making***	***Patient Care***	***Total***
Cardiologists (CC)	17%	12%	12%	8%	47%
Fellows (CF)	10%	14%	19%	1%	45%
Nurse Practitioners (NP)	1%	3%	4%	0%	8%
Total for all Participants	28%	28%	35%	9%	100%
Intensity	***Communication***	***Workflow***	***Medical Decision Making***	***Patient Care***	
Cardiologists (CC)	Negative	Very Negative	Negative	Very Negative	
Fellows (CF)	Neutral	Neutral	Neutral	Neutral	
Nurse Practitioners (NP)	Neutral	Neutral	Neutral	Neutral	
Convergence	***Communication***	***Workflow***	***Medical Decision Making***	***Patient Care***	
	Medium	Medium	High	Low	

Table 4. Theme identification by frequency, intensity and convergence.

Details by theme are presented in the discussion section below.

Quantitative Measures of Satisfaction and Effectiveness

Table 5 depicts the results of the independent quantitative analysis. SUS scores revealed that cardiologists and nurse practitioners were dissatisfied with EHR usability, where fellows were less critical of their interaction with the EHR. The mean score was 52.86, and overall satisfaction scores by participants ranged from 25 to 100. Using a t-distribution for this small sample, satisfaction scores range between 26.14 and 79.57, for a 95% confidence interval, well below satisfactory. The wide range of 54 points reflected the diversity of scores when considering the group as a whole. Looking at subgroups of providers, cardiologists rated system usability at 42 (a report card score of “F”), fellows at 75 (a more neutral score of “C“), and nurse practitioners at 60 (a “D”).

	Composite	***Cardiologists (CC)***	***Fellows (CF)***	***Nurse Practitioners (NP)***
SUS Composite Score Scale 0-100	57 (Grade = F)	42 (Grade = F)	75 (Grade = C)	60 (Grade = D)
Task Completion Mean Score	79	93	67	77

Table 5. SUS and Task Completion Scores by Provider role

Success scores for all 28 tasks were entered after review of the session. Overall, the group had a 79% mean task completion score. Cardiologists had a higher (93%) rate of success, followed by nurse practitioners at 77%; cardiology fellows successfully completed 67% of tasks.

Discussion

Issues surrounding EHR system usability are summarized in Table 6. For each theme, similarities between cardiologists, cardiology fellows, and nurse practitioners were noted, along with whether the comment was presented as positive or negative. For each theme, there were also topics where the groups diverged. These findings are discussed below.

<table>
<tr><th>Theme</th><th>Cardiologists (CC)</th><th>Fellows (CF)</th><th>Nurse Practitioners (NP)</th></tr>
<tr><td rowspan="2">Medical Decision Making</td><td colspan="3">+ Patient data available at point-of-care
- External data not well-integrated</td></tr>
<tr><td>+ Review patient data to formulate holistic view, then look for gaps

- less experienced users are led by the system to make decisions</td><td>+ collect detailed data, then build total view of patient</td><td>+ Interview patient, then look for inconsistencies in data</td></tr>
<tr><td rowspan="2">Communication</td><td colspan="3">+ EHR support of mail and fax saves time in notifications
+ All users are able to see information real-time, easily refreshed
- Large volume of information makes it difficult to find specific info</td></tr>
<tr><td>+ Self

+ Patient</td><td>+ Partners</td><td>+ PCP

+ Healthcare team</td></tr>
<tr><td rowspan="2">Workflow</td><td colspan="3">+ Templates allow pre-population of note from other data in EHR

- Completion of notes requires time outside of patient encounter</td></tr>
<tr><td>+ Data entry shared by support staff</td><td colspan="2">+ Use customizable features to reduce burden of data entry</td></tr>
<tr><td rowspan="2">Patient Care</td><td colspan="3">+ Ability to capture and validate patient data</td></tr>
<tr><td>+ Confirm match between patient and data

+ Confirm patient's understanding of diagnosis

- Notes contain wrong information that is carried forward</td><td>+ Confirm patient's understanding of problems</td><td>+ High level of interaction with patient, collecting data, assessing understanding of care plan</td></tr>
</table>

Table 6. Major themes across provider type

Medical Decision Making

Availability of patient data at the point-of-care was viewed by cardiologists, fellows and nurse practitioners as a key benefit provided by the EHR system. The groups agreed that patient data from external sources was difficult to find, and inconsistent in format. Cardiologists were most likely to use a top-down approach to assess an overall view of the patient, and rapidly search data that was important to decisions involving patient care. If data was missing from the EHR problem list, or it was present but inconsistent, the search for incomplete data became a priority for interaction with the patient.

> *"Problem lists cannot be trusted. It's not kept up well. But you have to spend some time looking through the notes… Monty Hall what's behind the curtain?" (CC)*

The three groups differed in several ways. Cardiologists were concerned that reliance on the EHR for decision support was a poor substitute for real-world experience and learning. The ability of EHR systems to make complexity simple was perceived to inhibit learning for complex decision-making and mask the underlying complexity of the decision.

> *"for a neophyte, they don't have experience and trial by fire, they will be led by the system - a very corrupting process" (CC)*

Fellows were systematic in their collection of patient data, and assembled their view of the patient from the data elements, using a bottom-up approach. The group was technically skilled at using EHR functionality including the problem list, order entry, and med reconciliation to collect and validate data required by the system, and derived their satisfaction from the ability to find and input essential data elements, more than the use of that data as input to a medical decision.

Nurse practitioners also used a systematic approach, focusing first on their interaction with the live patient, and then resolving inconsistencies with EHR data they had reviewed during their preparation for the patient visit.

Communication

Cardiologists, fellows and nurse practitioners all agreed that the ability to share patient data in real-time, with multiple providers, both within the clinic and external to the institution was a benefit of the EHR. The need to share information via email or written notification was often a time-consuming process prior to the improved efficiency of communication provided by the EHR system.

The groups had differing views on the receiver of communication generated by the EHR from the data they collected. Cardiologists viewed documentation as way to capture patient information for their own use and were concerned about carrying bad information forward and its potential adverse impact on patient care. Cardiologists often looked first for their own notes, which they deemed to be trustworthy. When documenting, they included items that they believed most relevant, in an effort to reduce the cognitive load of reviewing a returning patient's data.

" … allows me to separate the signal from the noise… " (CC)
" My motto is "I don't trust anybody, I look it up myself" (CC)

Fellows commented that they captured information for review with their attending cardiologist, and the value of the after visit summary data for the patient. Nurse practitioners were likely to follow up on the identification of a primary care provider if one was not documented.

Workflow

The ability to pre-populate a clinical note from information collected during the patient encounter was seen by cardiologists, cardiology fellows, and nurse practitioners to reduce the overall amount of time needed to complete documentation for a patient visit. While this was beneficial, the use of template-style notes was viewed as potentially harmful, in that incorrect or outdated information was sometimes carried forward into a current note. Nearly all expressed concern about the inability to complete documentation close to the patient visit, with completion often delayed until after the clinic schedule ended.

Cardiologists made use of staff to support the time-consuming entry of patient data into the EHR system. The collaboration allowed the cardiologist valuable time to search out relevant, sometimes elusive data to interpret a patient's condition and determine appropriate care.

"… I dig through notes, imaging, labs, it's a mystery.." (CC)

Fellows utilized EHR functionality to create custom phrases to cut down on data entry effort needed for common information. Most were fast typists, and were more tolerant of complex workflows involving many keystrokes and mouse-clicks.

Patient care

All participants expressed concern that patients understand the nature of their problem and their care plan. The individual groups also exhibited differences. Cardiologists assigned a high level of importance to establishing the credibility of the documentation, and focused on the most current problems presented by the patient. If this information was incorrect, then much of the data could be deemed irrelevant.

"Need to find out why the patient is there 30% of the time the note is in error…" (CC)
"… notes are often templated and people carry wrong information forward …" (CC)

" … Now there are inconsistencies - how do I rely on anything in the record after this?" (CC)
"… chart review - difficult to pick out my name, or cardiology, difficult to pick out relevant stuff, there may be lots of providers involved with this patient …" (CC)

Cardiology fellows and nurse practitioners demonstrated a high level of awareness on the need for maintaining a good relationship with the patient during the encounter.

"… patients are complex, I need to establish rapport…" (CF)

In addition, fellows were observed as less likely to question the patient, perhaps due to the customary follow-up of their attending physician.

Recommendations

Overall, the study was able to identify different usability needs for cardiologists, cardiology fellows, and nurse practitioners, however gaps exist in several key areas. Provider type and experience suggest different requirements for EHR functionality for patient care. Firstly, medical decision-making is viewed differently by the experienced cardiologist, who is able to sort for relevance and validity of the many elements of patient data stored within the EHR. Cardiology fellows, who have less clinical experience may benefit from EHR systems that guide their organization and prioritization of individual data elements, so that a higher-level view of the patient becomes visible. Nurse practitioners may have a differing level of responsibility for medical decisions, and are a critical point in assuring the validity of the more granular elements of data for use in decision-making. Secondly, communication needs were important to all providers, but also varied by type of provider. Cardiologists expressed a need to sort for their own notes first, and to access other notes as needed. Fellows shared the need for complete and accurate documentation, but were less likely to assess a higher priority to their own documentation, but might search for their attending physician's notes. Thirdly, solutions to workflow may involve use of EHR systems that extend beyond the use of templates and copy-and-paste features, supporting collaborative data entry by different members of the healthcare team, ensuring that the collection of data is aimed at high quality rather than high volume data. Cardiologists were reluctant to view this solely as a technology solution, while cardiology fellows were pleased by their ability to customize their own data-collection tools. Lastly, EHR designs for patient care must ensure that patient data is valid, and that the patient is highly engaged and informed about their own health issues. Cardiologists were most likely to detect inconsistencies between the patient's story and accept responsibility for the potential harm of incorrect data. Fellows and nurse practitioners held their focus on interaction with the patient, with less awareness of inconsistent data.

Limitations

The study may have limited generalizability as it focused on a small sample and is limited to one EHR system. The sample chosen from cardiology may not be representative of all medical practices; however, it supports the need for focus on usability based both on type of practice and user type. In addition, other user types may be considered for future study, extending the study beyond cardiologists, fellows, and nurse practitioners to include medical support staff as well as primary care providers. The findings from this small sample indicate opportunities for future study.

Conclusion

Using an HCI-based approach, we were able to detect differences between cardiologists, cardiology fellows, and cardiology nurse practitioners, and to propose a set of design guidelines based on actual user needs. In addition, the evaluation framework that was proposed was demonstrated as a robust tool. Usability studies took take place in an actual clinical environment, overcoming limitations associated with the artificial settings of traditional usability testing. These findings provide a foundation for future work to optimize EHR functionality in a complex and changing environment.

Chapter 7 – The Journey of EHR Optimization

In economics, optimization is to make the best of something, whether a decision, a design or a system [75-77]. As a mathematical technique, optimization finds the best fit of a function consisting of several variables, and subject to a set of constraints, and results in a solution that maximizes desired factors, while minimizing the undesirable. In this study, the journey of EHR optimization requires the input of content and technical experts, along with diverse and representative users to address constraints and identify desirable factors, to make the EHR system a more integrated tool used in the diagnosis and care of patients. EHR optimization considers constraints such as time or money, and desired factors may include the use of a particular device, the level of information provided on a page, the ability to customize, or the size of a display. Most importantly, a meta-structure must be in place to allow for capture of all of the nuances of user –EHR interactions.

Chapters 3 and 4 were conducted at a time when EHR systems were viewed as innovative and untested. Adoption was a matter of choice, whether by academic institutions, or by private practices. Physicians were often viewed as late adopters, and resistant to change. The latter study focused specifically on early adopters. Both groups of physicians, despite their differing propensity for technology, expressed concerns about workflow, communication, decision support and patient care. As EHR usage became prescribed through public policy, adoption became a mandate, moving EHR study away from adoption and toward usability. Chapter 5 focused on the design of a prototype to study how EHR systems were used within a realistic context. A mobile usability framework was designed to take EHR usability studies out of a testing laboratory and into the clinic.

These studies confirmed the need for detection of differences in the usability of electronic health record systems using a human-computer interactions framework. Chapter 6 provides an additional step toward EHR optimization by specifying a framework with the EHR user as the center of design activity, using a tool that was flexible enough to be taken into the clinical environment without violating HIPAA concerns for patient privacy. The study validated a conceptual framework that included a complex clinical scenario developed by content experts, a simulated patient, and a mobile usability testing lab. This framework grew from unsuccessful attempts to introduce EHR functionality using a traditional software development approach. Healthcare providers were recipients of well-intentioned attempts to "cut and paste" the successes of information technology into the wickedly complex domain of healthcare. EHR changes often rippled into the larger social context – changing work roles, power structures, business processes, and often introducing unintended consequences as resourceful users attempted to adapt.

In addition, the convergent parallel mixed methods study design allowed for the "how?" questions of quantitative methods to be combined with the "what and why?" questions of qualitative approaches. This holistic view was especially suited to the complexities of healthcare, and paves the way for far-reaching implications for changing the nature of healthcare work by allowing new insight into EHR usability. The framework emerged as a novel and innovative way to evaluate EHR usability.

Recommendations for EHR Design

Findings resulting from this research are important to future EHR design activity. Major points include:

1. A flexible usability testing framework is necessary to capture requirements in functionality required by different groups of providers the design of EHR systems. The framework will be essential in assessing the impact of future changes in EHR designs.
2. EHR designs must support differing levels of domain knowledge and technology affinity within a provider practice type. These user characteristics may strongly influence future EHR design decisions and deserve further study.
3. Improvements in EHR designs that support medical decision making, communication, patient care and provider workflow are key components for EHR optimization. These four areas will provide high-impact areas based on provider observation and prioritization.

What's next

Clearly, providers are not satisfied with current EHR solutions, despite their ubiquitous presence in nearly every facet of healthcare work. Future work to propel EHR optimization must include the use of a robust EHR evaluation framework that takes a holistic view in assessing the experience of users. Future studies will expand this approach to include different user types from within a practice, different practices outside of cardiology, and different institutions with a variety of EHR systems.

The study of EHR optimization is currently nascent. However, it holds the promise of novel and innovative insight for better integration of information technology into the practice of medicine.

Appendix A: Cognitive Walkthrough Scoresheet

Task Assignment	Easily Completed	Completed with difficulty	Not completed	Task Time	Correct Path	Minor Deviations	Major Deviations	Target Task Time	Participant Task Rating 1=Very Easy to 5=Very Difficult
1 - Document nitroglycerin under the tongue given in the ER by a nurse per verbal order 3 hours after admission									
2 - Enter vital signs [Blood pressure (BP) 172/95, heart rate 90]									
3 - Order labs									
4 - Modify active medications									
5 - Review labs									
6 - Document DNR status									
7 - Determine status of STAT medication that was ordered a few hours before									
8 - Return to finish the documentation for the handoff									
9 - Day 2. Review morning labs and vital signs									
10 - Transfer all inpatient medications to outpatient medications									
11 - Print discharge summary									
12 - Print a report for a hospital administrator that shows how the organization is doing on the quality measure about how soon nitroglycerine is given to patients with chest pain in the emergency department.									

Adapted from NISTIR 7804 - Technical Evaluation, Testing, and Validation of the Usability of Electronic Health Records, 2010.

Appendix B. Scenario Development Blueprint

Training and Using SPs for Teaching and Assessments

Case Development Blueprint:

Presenting Complaint:	Routine cardiology clinic follow-up for multiple cardiac conditions: atrial fibrillation, hypertension, coronary artery disease and heart failure
Gender and age:	67 year old male
Case Name:	Cardiology Clinic-Routine follow-up
Key Objectives:	To test the interactions between the research subject and the electronic health record (Human-Computer Interaction, HCI).
Brief summary:	This simulated patient will have a strong back story of cardiac conditions. They are showing up for routine follow-up without a specific complaint. There are guidelines and measures that suggest what a patient should be taking, what labs they should have and what sort of testing is required.
Differential Diagnosis: **(diagnosis in parens)**	Not Applicable
Task(s) for examinee:	Review existing records, obtain a current history and physical examination, review medications, prescribe medications, develop a note and communicate with the referring physician
Exam Room Needs:	Computer
Post-Encounter Station Needs:	None
Data collection tool(s):	Paired computer, observer to document, moderator
Designed for:	Physicians and other cardiology providers (NPs and PAs)
Case Authors:	John Windle MD Reviewed by James Tcheng MD
Date	January 15, 2014

SP Training Notes:

Case Name	Cardiology Clinic-Routine follow-up
Presenting Situation	Here for annual follow-up with their cardiologist
Psychosocial Profile	Friendly, polite but not spontaneous, responds to direct questions but doesn't amplify on them
Opening Statement	How are you today?
History of Present Illness	Bill has no new complaints. He does not have angina when he exercises, he has not required any nitroglycerin. He sleeps well at night without any additional pillows and doesn't wake up at night short of breath. He walks a mile three times a week and it takes him about 30 minutes. He does get a little short of breath climbing up a flight of stairs but doesn't have to stop. He denies any palpitations, lightheadedness or syncope. He has had no major bleeding issues. He does notice some intermittent constipation and gets up once per night to urinate. He has no leg swelling but occasionally his back bothers him.
Allergies	Review allergies, document new allergies
Past Medical Hx	He has a twenty year history of hypertension and probably didn't take care of himself as he should. Five years ago he suffered an anterior myocardial. He went to the cath lab and had a stent placed. He was on vacation at the time and doesn't remember the name of the Hospital. He had congestive heart failure diagnosed and was put on medications. Three years ago he was hospitalized with shortness of breath and was found to have atrial fibrillation.
Social Hx	Bill is a married 67 year old male, retired from his job as a high school teacher. He is a non-smoker and has a beer every once in a while. He likes reading. He exercised three times per week at the Gym and he and his wife enjoy cooking Mediterranean food.
Family Medical Hx	His father died of lung cancer at 72 years of age, he was a heavy smoker. His mom died of pneumonia when she was 81. He has a brother who has had coronary bypass surgery
Physical Exam Findings:	Lungs clear, CV Regular Rate no murmurs or S3, no bruits, abdomen non-tender, extremities, no edema, 2+ pulses, no JVD no carotid bruits
Special Instructions:	Will have EKG, echocardiogram and CXR reports, will have pertinent lab and medications.
Order:	Place orders for medications/ labs
After Visit Summary:	Level of service

Appendix C. Routine Clinical Visit Scenario: Patient Data

PRESENTING SITUATION:

Patient Name (with age):

Bill 67 years of age

Setting: Clinic

Vitals:	Height	5’11” (1.8303 m)
	Weight	205 lb 11 oz (93.3 kg)
	Temp	37
	RR	15
	BP	142/80
	HR	52
	Pain	none

Complaint: Patient here for routine follow-up

Appendix D. Routine Clinical Visit Scenario: Previous Clinic Note

12/3/2013 11:15 AM Office Visit

Diagnoses

Atrial fibrillation – 427.31

Ischemic cardiomyopathy – 414.8

Coronary atherosclerosis – 414.00

Hypertension 401.9

Primary Care Provider: Mark N Time MD

CC:

Chief Complaint

Patient presents with routine clinical follow-up

HPI: This is a 67 y.o. male with coronary artery disease, ischemic cardiomyopathy, ef 35%-40% (echo 2010), PAF, CHF and hypertension. The patient has been doing well over the last year without any problems. He has had two episodes of afib and he remains on coumadin with his INR's followed by the VA. He is not dizzy or lightheaded and denies chest pain, pressure or palpitations.

Medications:

- aspirin 325 MG tablet. Take 1 tablet by mouth 1 (one) time a day
- glucosamine-chondroitin 500-400 mg cap. Take 1 capsule by mouth 1 (one) time a day.
- lisinopril (PRINIVIL, XESTRIL) 5 MG tablet. Take 5 mg by mouth 1 (one) time a day.
- rosuvastatin (CRESTOR) 20 MG tablet. Take 1 tablet by mouth 1 (one) time a day.
- solatol (BETAPACE 80 MG tablet. Take 1 tablet by mouth 2 (two) times a day.

- warfarin (COUMADIN) 7.5 MG tablet. Take 1 tablet by mouth 1 (one) time a day. As directed.

Allergies

Allergen reactions:

- levaquin (Levofloxacin)
- Succinylcholine
- Systemic depression

ROS:

General: No significant weight changes. No appetite changes. No fevers chills, excessive tiredness or fatigue

HEENT: No swallowing difficulty, nosebleeds, poor dentition, visual changes, or hearing charges.

Skin: no ulcers, sores rashes

Respiratory: no cough, SOB, excessive phlegm, wheezing, snoring.

Cardiac: as per HPI

Abdomen: no bloating, abdominal pain, change in bowel habits, nausea / vomiting, no heartburn or indigestion.

Kidney/ Bladder: no urinary symptoms, no dysuria, no hematuria

Neurological: no lightheadedness, weakness, numbness, tingling, HA, frequent galls, no chest wall pain, or radicular symptoms

Blood: no easy bruising / blooding, blood clots liver inflammation, anemia or cancer

Endocrine: no weight change, dry skin, constipation, e excessive thirst, cold/heat intolerance

MS: no painful joints, joint effusions. Swollen joints, or muscles pain

Past Medical History

Diagnosis Date

- Coronary atherosclerosis 10/17/2008
- Ischemic cardiomyopathy 10/17/2008

- Atrial fibrillation – 7/1/2010
- Hypertension – 3/23/2010
- Hyperlipidemia – 3/23/2010

Past Surgical History

Coronary Stent 5 years ago in Cleveland, doesn't' remember which hospital

PE:

BP 108/70 | Pulse 65 | Temp 36.7^{o} C | Resp 22 | Ht 5'11" (1.8303 m) | Wt 205 lb 11 oz (93.3 kg) | BMI 28.69 kg/m2 | SpO2 94%

Wt. readings from last 3 encounters:

08/01/201x 205 lb 11 oz (93.3kg)

Body mass index is 28.69 kg/(m^2).

General: alert, well oriented x 3.

Neck No JVD. Carotid upstrokes are normal without bruits.

Chest: Nontender. Normal in appearance.

Cardiac: RRR, S1, S2, no murmur, rub or gallop. No heaves are appreciated. PMI nondisplaced.

Lungs: Clear to auscultation, no crackles or wheezes.

Abdomen: soft, non-tender, non-distended. BS(+)

Extremities: no clubbing, cyanosis, or edema. DP, PT pulses are 2+ bilaterally.

Neuro: CN 2-12 are grossly intact. Otherwise exam is nonfocal.

Musculoskeletal: Strength is equal 5/5 in all extremities.

Psych: Cooperative and calm. Appropriate mood.

Lab Results – Previous Year

Component Value

WBC 11.8*

HGB 14.1

HCT 44.0

PLT 114*

NA 144

K 4.2

CL 110

CO2 29

BUN 13

CREA 0.87

CALCIUM 8.7*

TRIG 83

HDL 33*

LDLCALC 79

GLUCOSE 140*

MCV 94.0

Assessment:

1. Atrial fibrillation. Electrocardiogram clinic
2. Ischemic cardiomyopathy
3. Coronary atherosclerosis
4. Hypertension – stable

Plan: We will see if he’s had a recent echo. If he has not had one recently he will have an echo with his next appointment to review his LV function. The patient was agreeable and will call if he has concerns prior to his next appointment.

Appendix E. Routine Clinical Visit Scenario: Patient Data: Echocardiogram Results

Date: 11/6/2014
Echocardiogram2D complete, contrast if needed

Details
Patient Location: ECHO
BP: 106/57 mmHg
HR:61

Performed by Elizabeth Neuroth, RDCS

MMode/2D Measurements and Calculations
RVDd: 3.5 cm LVIDd:6.2 cm EDV(Teich):194.1 ml Ao root
Diam: 3.7 cm
IVSd: 1.2 cm LVIDs: 4.6 cm ESV(Teich):99.0 ml LA

LVOT diam: 2.4 cm EF(MOD-sp4):42.1%

LVOT area:4.6 cm2

Doppler Measurements & Calculations
MV E max vel: MV V2max: MV dec time:0.14 sec Ao V2
Max:
81.4 cm/sec 58.7 cm/sec 101.8
Cm/sec
MV A max vel: MV max PG: 1.4 mmHg Ao V2
Mean:
40.6 cm/sec MV V2 mean: 68.6
Cm/sec
MV E/A: 2.0 24.3 cm/sec Ao V2
VTI: 22.6cm
MV mean PG: 0.30 mmHg
AVA(I,D): 3.7 cm2
MV V2 VTI: 13.0 cm
MVA(VTI): 6.4 cm2
AVA(V,D): 4.3 cm2

LV V1 max PG:3.7 mmHg MR max vel: PA V2
Max:
LV V1 mean PG: 2.1 mmHg404.3 cm/sec MR PISA: 0.59 cm2 68.5
Cm/sec
LV V1 max: 95.4 cm/sec MR max PG: 65.4 mmHg MR ERO: 0.05 cm2 PA max
PG: 1.9 mmHg
LV V1 mean: 68.8 cm/sec MR PISA radius: PA V2
Mean:
LV V1 VTI: 18.2 cm 0.31 cm 44.6
Cm/sec
MR alias vel: PA mean
PG:
30.8 cm/sec 0.98
mmHg
PA V2
VTI: 13.9 cm

PI end-d vel: TR max PG: 26.7 mmHg AVA (Dim Index):
137.1 cm/sec
.94 cm2

Rhythm
Av Sequential Paced.

Left Ventricle
LV Mass 196 g/m. Dilated hypertrophied LV with moderately depressed systolic function.
Left ventricular end diastolic volume 159 ml. Left ventricular end systolic volume 92 ml.
Left Ventricular ejection fraction = 30 – 35%. There is apical akinesis.

Right Ventricle
RV dimension 3.5 cm. There is a pacemaker lead in the right ventricle. The right ventricle is normal in size and function. There is normal right ventricular wall thickness.
Right ventricular S' 10 cm/s.

Atria
LA Volume 47 ml/m2. The left atrium is severely dilated. The right atrium is moderately dilated. RAQ filling pressure 10 mmHg. Interatrial septum intact by color doppler.

Mitral valve
Structurally normal mitral valve with trace mitral regurgitation. EROA 0.04 cm2.

Tricuspid valve
Insufficient TR to assess PASP.

Aortic valve
Structurally normal aortic valve with no aortic insufficiency.

Pulmonic valve
There is no pulmonic valvular stenosis. Trace pulmonic regurgitation.

Great vessels
The aortic root is normal size.

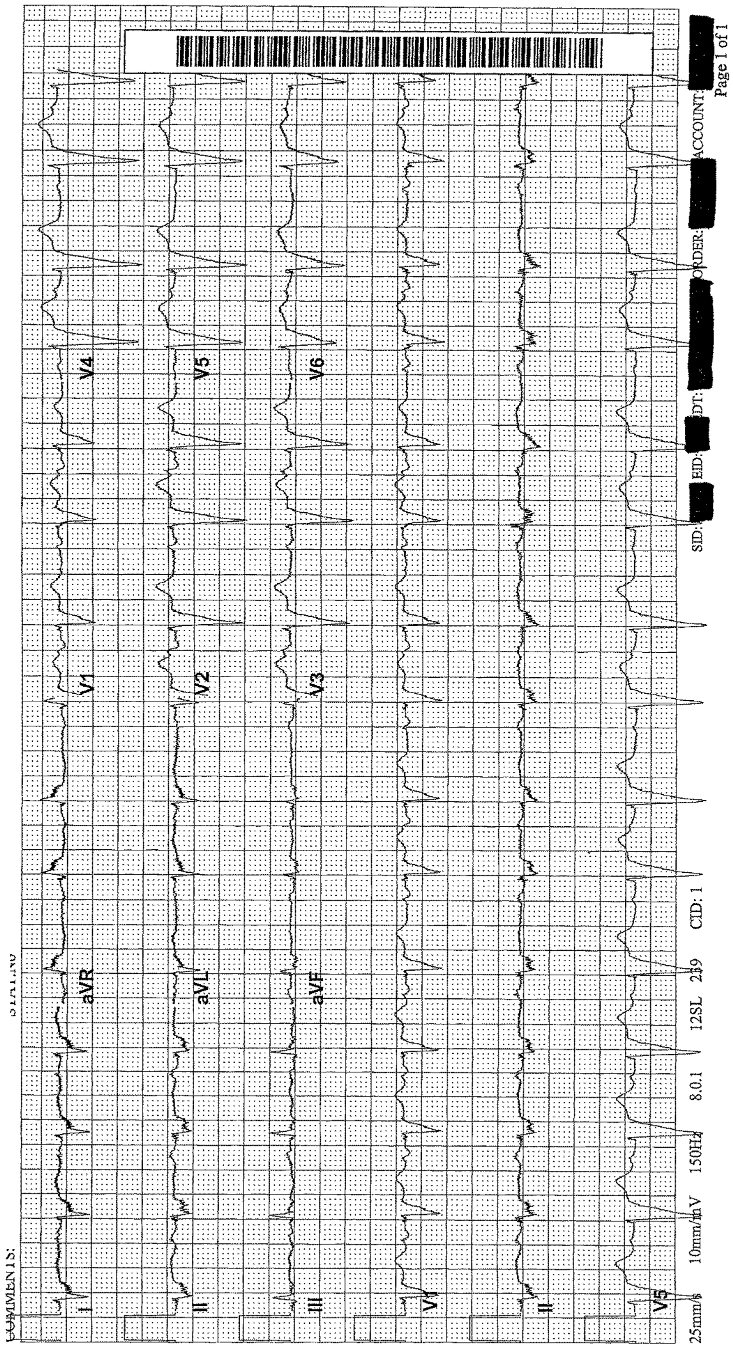
Pericardium/ Pleural
Trace pericardial effusion

Hemodynamics
E = 85. E' = 13. LA Pressure = 36 mmHG.

Contrast agent Definity used for left ventricular function. Contrast administered by Michele Murphy RN. Amount of Definity used: 1.5 ml. Side effects associated w/contrast none. Arrhythmias associated w/contrast none.

Conclusions:
There is apical akinesis.
Dilated hypertrophied LV with moderately depressed systolic function.
The right atrium is moderately dilated
The left atrium is severely dilated.
Structurally normal mitral valve with trace mitral regurgitation.
Trace pulmonic regurgitation.
Trace pericardial effusion.
Minor decrease in LV EF since 6/5/13.

Appendix F. Routine Clinical Visit Scenario: Patient Data: EKG



Appendix G. Routine Clinical Visit Scenario: Patient Data: Labs

Lab Results: 12/2/2014

CBC	
WBC	9.8
RBC	4.02
Hemoglobin	12.7
Hematocrit	39.7
MCV	98.8
MCHC	32.0
RDW	13.2
Platelet Count	267
DIFFERENTIAL	
Neutrophils Relative	66
Lymphocytes Relative	21
Monocytes Relative	8
Eosinophils Relative	3
Basophils Relative	1
Immature Neutrophi…	1
nRBC	0
Type of Diff Done	Automated Diff
Automated Abs Neut…	6.6 *
Lymphocytes Absolute	2.1
Monocytes Absolute	0.8
Eosinophils Absolute	0.3
Basophils Absolute	0.1
Immature Neutrophi…	0.1
CHEMISTRY PANELS	
Cholesterol	184*
Triglycerides	176*
HDL Cholesterol	76*
LDL Cholesterol	73*
VLDL Cholesterol	35*
Chol/HDL Ratio	2.4*
THYROID STUDIES	
Free T4	0.8
TSH Ultrasensitive	4.850

Appendix H. Routine Clinical Visit Scenario: Patient Data: Stress test

NM gated heart MUGA rest study

Date: 10/21/2010

Status: final Results

Dx: Cardiomyopathy

Details
Gated MUGA Scan.

Impression:
1. Calculated left ventricle ejection fraction of 39%
2. Inferolateral wall hypokinesis, suspicious for infarction sequel

History: 67 – year-old male with history of cardiomyopathy and history of CABG.

Technique: 3-ML of whole blood was withdrawn from the patient. Red blood cells were labeled with 26 mCi of Technetium 99m sodium pertechnetate. Blood was then re-administered without adverse reaction. Gated planar imaging of the myocardium was performed in anterior, lateral and LAO projections, with an angle of 60 degrees and tilt of 3 degrees. Time activity curves were generated and Left ventricle ejection fraction was then calculated.

Findings: Left ventricular ejection fraction measure 39%. There is inferior lateral wall hypokinesis, this is suspicious for infarct.

Thank you very much for this consultation.

I have participated in the interpretation of these images and approved this report.

Appendix I. System Usability Survey Instrument

EHR Usability Study - System Usability Survey

Participant:	Strongly disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)
1. I like using this system.	☐	☐	☐	☐	☐
2. I found the system unnecessarily complex	☐	☐	☐	☐	☐
3. I thought the system was easy to use	☐	☐	☐	☐	☐
4. I think that I would need the support of a technical person to be able to use this system	☐	☐	☐	☐	☐
5. I found the various functions in this system were well integrated	☐	☐	☐	☐	☐
6. I thought there was too much inconsistency in this system	☐	☐	☐	☐	☐
7. I would imagine that most people would learn to use this system very quickly	☐	☐	☐	☐	☐
8. I found the system	☐	☐	☐	☐	☐

very cumbersome to use					
9. I felt very confident using the system	☐	☐	☐	☐	☐
10. I needed to learn a lot of things before I could get going with this system	☐	☐	☐	☐	☐
11. Overall, I am satisfied with the system	☐	☐	☐	☐	☐

Appendix J. Task Completion Scorecard

Task Success Scores			Individual Scores									Group Mean Scores		
			CC1	CC2	CC3	CC4	CF1	CF2	CF3	NP1	NP2	Cardiologist	Fellow	Nurse practitioner
T1	Coronary Artery Disease	Myocardial Infarction	1	1	1	1	1	0	1	0	1	100	67	50
T2		Stent present	1	1	1	1	0	1	1	0	0	100	67	0
T3		Smoking status	0	1	0	1	0	0	0	1	1	50	0	100
T4		Angina classification	1	1	1	1	0	0	0	1	1	100	0	100
T5		Medications – statin	1	1	1	1	1	1	1	1	1	100	100	100
T6		Medications – antiplatelet	1	1	1	1	1	1	1	1	1	100	100	100
T7		Medications – Beta blocker	1	1	1	1	1	0	1	1	1	100	67	100
T8		Exercise	1	1	1	1	1	1	1	1	0	100	100	50
T9		Lipid profile	1	1	1	1	1	0	1	1	0	100	67	50
T10	Heart Failure	NYHA	1	1	1	1	1	0	1	1	0	100	67	50
T11		Symptoms (dyspnea, orthopnea, exertional SOB)	1	1	1	1	1	1	1	1	1	100	100	100
T12		HF Education	1	1	0	1	0	0	1	0	0	75	33	0
T13		ICD Counseling	1	1	1	1	0	1	1	0	0	100	67	0
T14		Medications – ACB / ARB	1	1	0	1	1	0	1	1	1	75	67	100

Task Success Scores			Individual Scores									Group Mean Scores		
			CC 1	CC 2	CC 3	CC 4	CF 1	CF 2	CF 3	NP 1	NP 2	Cardiologist	Fellow	Nurse practitioner
T15		Medications – Beta blocker	1	1	1	1	1	0	1	0	1	100	67	50
T16		Ejection Fraction	1	1	1	1				1	1	100	0	100
T17	Atrial Fibrillation	Antithrombotic therapy	1	1	1	1	1	1	1	1	1	100	100	100
T18		Symptom assessment	1	1	1	1	1	1	1	1	1	100	100	100
T19		CHADS2VASC	1	1	1	1	0	1	1	0	0	100	67	0
T20	Hypertension	BP at target	1	1	0	1	1	1	0	1	1	75	67	100
T21		Hypertensive Medications	1	1	0	1	1	1	0	1	1	75	67	100
T22	Check medication needs		1	1	1	1	1	1	1	1	1	100	100	100
T23	Patient education		1	1	1	1	1	1	1	1	1	100	100	100
T24	After visit summary		0	1	1	1	1	0	0	1	1	75	33	100
T25	Level of service		0	1	1	1	0	1	0	1	1	75	33	100
T26	Generates a note		1	1	1	1	1	1	1	1	1	100	100	100

T27	Note to Referring physician		1	1	1	1	0	0	1	1	1	100	33	100
Task Success Scores			**Individual Scores**									**Group Mean Scores**		
			CC 1	CC 2	CC 3	CC 4	CF 1	CF 2	CF 3	NP 1	NP 2	Cardiologist	Fellow	Nurse practitioner
T28	Uses order entry		0	1	2	1	1	1	1	1	1	100	100	100
Mean Success Rate by role												93	67	77
Overall mean														79

Bibliography

1. Stiroh KJ. Information technology and the US productivity revival: what do the industry data say? Am Econ Rev 2002:1559-1576.

2. Brynjolfsson E, Hitt LM. Beyond computation: Information technology, organizational transformation and business performance. The Journal of Economic Perspectives 2000:23-48.

3. Bulger RJ, Barbato AL. On the Hippocratic Sources of Western Medical Practice. Hastings Cent Rep 2000 Jul. - Aug.;30(4):S4-S7.

4. Reiser SJ. The Clinical Record in Medicine Part 2: Reforming Content and Purpose*. Annals of Internal Medicine 1991 June 1;114(11):980-985.

5. Reiser SJ. The Clinical Record in Medicine Part 1: Learning from Cases*. Annals of Internal Medicine 1991 May 15;114(10):902-907.

6. Gillum RF. From Papyrus to the Electronic Tablet: A Brief History of the Clinical Medical Record with Lessons for the Digital Age. Am J Med 2013 10;126(10):853-857.

7. Collen MF. Fifty years in medical informatics. Yearb Med Inform 2006:174-179.

8. Weed LL. Medical records that guide and teach. N Engl J Med 1968 Mar 14;278(11):593-600.

9. Leape LL. Human factors meets health care: The ultimate challenge. Ergonomics in Design: The Quarterly of Human Factors Applications 2004;12(3):6-12.

10. Richard S. Dick EBS, Don E. Detmer E, Committee on Improving the Patient Record,Institute of Medicine. The Computer-Based Patient Record:An Essential Technology for Health Care, Revised Edition. : The National Academies Press; 1997.

11. Bush GW. Executive Order 13335: Incentives for the Use of Health Information Technology and Establishing the Position of the National Health Information Technology Coordinator.

;2010(4/6/2010).

12. Hillestad R, Bigelow J, Bower A, Girosi F, Meili R, Scoville R, et al. Can electronic medical record systems transform health care? Potential health benefits, savings, and costs. Health Aff (Millwood) 2005 Sep-Oct;24(5):1103-1117.

13. Taylor R, Bower A, Girosi F, Bigelow J, Fonkych K, Hillestad R. Promoting health information technology: is there a case for more-aggressive government action? Health Aff (Millwood) 2005 Sep-Oct;24(5):1234-1245.

14. Goodman C. Savings in electronic medical record systems? Do it for the quality. Health Aff (Millwood) 2005 Sep-Oct;24(5):1124-1126.

15. Public Law 111–5 111th Congress. American Recovery and Reinvestment Act of 2009 . 2009.

16. Klein K. So much to do, so little time. To accomplish the mandatory initiatives of ARRA, healthcare organizations will require significant and thoughtful planning, prioritization and execution. J Healthc Inf Manag 2010 Winter;24(1):31-35.

17. Classen D, Bates DW, Denham CR. Meaningful Use of Computerized Prescriber Order Entry. Journal of Patient Safety 2010;6(1).

18. Federal Register. Medicare and Medicaid Programs; Electronic Health Record Incentive Program—Stage 2. ;2013(1/2/2013).

19. Office of the National Coordinator for Health Information Technology (ONC), Department of Health and Human Services. Health information technology: initial set of standards, implementation specifications, and certification criteria for electronic health record technology. Final rule. Fed Regist 2010 Jul 28;75(144):44589-44654.

20. Kellermann AL, Jones SS. What It Will Take To Achieve The As-Yet-Unfulfilled Promises Of Health Information Technology. Health Affairs 2013 January 01;32(1):63-68.

21. Bates DW. Physicians and ambulatory electronic health records. Health Aff (Millwood) 2005 Sep-Oct;24(5):1180-1189.

22. Fossum M, Ehnfors M, Fruhling A, Ehrenberg A. An evaluation of the usability of a computerized decision support system for nursing homes. Applied Clinical Informatics

2011;2(4):420-436.

23. Harrison MI, Koppel R, Bar-Lev S. Unintended consequences of information technologies in health care--an interactive sociotechnical analysis. J Am Med Inform Assoc 2007 Sep-Oct;14(5):542-549.

24. Balfour DC,3rd, Evans S, Januska J, Lee HY, Lewis SJ, Nolan SR, et al. Health information technology--results from a roundtable discussion. J Manag Care Pharm 2009 Jan-Feb;15(1 Suppl A):10-17.

25. Eslami S, de Keizer NF, Abu-Hanna A. The impact of computerized physician medication order entry in hospitalized patients--a systematic review. Int J Med Inform 2008 Jun;77(6):365-376.

26. Lorenzi NM, Novak LL, Weiss JB, Gadd CS, Unertl KM. Crossing the implementation chasm: a proposal for bold action. J Am Med Inform Assoc 2008 May-Jun;15(3):290-296.

27. Campbell EM, Guappone KP, Sittig DF, Dykstra RH, Ash JS. Computerized provider order entry adoption: implications for clinical workflow. J Gen Intern Med 2009 Jan;24(1):21-26.

28. Devine EB, Williams EC, Martin DP, Sittig DF, Tarczy-Hornoch P, Payne TH, et al. Prescriber and staff perceptions of an electronic prescribing system in primary care: a qualitative assessment. BMC Med Inform Decis Mak 2010 Nov 19;10:72.

29. Mador RL, Shaw NT. The impact of a Critical Care Information System (CCIS) on time spent charting and in direct patient care by staff in the ICU: a review of the literature. Int J Med Inform 2009 Jul;78(7):435-445.

30. Unertl KM, Weinger MB, Johnson KB, Lorenzi NM. Describing and modeling workflow and information flow in chronic disease care. J Am Med Inform Assoc 2009 Nov-Dec;16(6):826-836.

31. Windle T, McClay J, Windle J. The Impact of Domain Knowledge on Structured Data Collection and Templated Note Design. Applied clinical informatics 2013;4(3):317-330.

32. Grabenbauer L, Skinner A, Windle J. Electronic Health Record Adoption – Maybe It's not about the Money Applied Clinical Informatics 2011;2(4):460-471.

33. Shortliffe EH. Strategic action in health information technology: why the obvious has taken so long. Health Aff (Millwood) 2005 Sep-Oct;24(5):1222-1233.

34. Charles, D, Gabriel, M, et al. Adoption of Electronic Health Record Systems among U.S. Non-federal Acute Care Hospitals: 2008-2013. ONC Data Brief 2014(16).

35. Hsiao C, Hing E,. Use and Characteristics of Electronic Health Record Systems Among Office-based Physician Practices: United States, 2001–2013. National Center for Health Statistics Products 2014;Data Briefs - Number 143(10/24/2014).

36. Friedberg MW, Chen PG, Van Busum KR, Aunon F, Pham C, Caloyeras J, et al. Factors Affecting Physician Professional Satisfaction and Their Implications for Patient Care, Health Systems, and Health Policy. : Rand Corporation; 2013.

37. Love JS, Wright A, Simon SR, Jenter CA, Soran CS, Volk LA, et al. Are physicians' perceptions of healthcare quality and practice satisfaction affected by errors associated with electronic health record use? J Am Med Inform Assoc 2012 Jul-Aug;19(4):610-614.

38. Abramson EL, Malhotra S, Fischer K, Edwards A, Pfoh ER, Osorio SN, et al. Transitioning between electronic health records: effects on ambulatory prescribing safety. J Gen Intern Med 2011 Aug;26(8):868-874.

39. Centers for Disease Control and Protection. CDC - DHDSP - Heart Disease Facts Available at: http://www.cdc.gov/heartdisease/facts.htm. Accessed 5/9/2013, 2013.

40. Ford ES, Ajani UA, Croft JB, Critchley JA, Labarthe DR, Kottke TE, et al. Explaining the decrease in U.S. deaths from coronary disease, 1980-2000. N Engl J Med 2007 Jun 7;356(23):2388-2398.

41. Go AS, Mozaffarian D, Roger VL, Benjamin EJ, Berry JD, Borden WB, et al. Heart Disease and Stroke Statistics—2013 Update: A Report From the American Heart Association. Circulation 2013 January 01;127(1):e6-e245.

42. Grabenbauer L, Fraser R, McClay J, Woelfl N, Thompson CB, Cambell J, et al. Adoption of electronic health records: a qualitative study of academic and private physicians and health administrators. Appl Clin Inform 2011 May 25;2(2):165-176.

43. Rogers EM. Diffusion of innovations New York: Free Press; 1995.

44. Information technology diffusion: a review of empirical research. ICIS; 1992.

45. Cooper RB, Zmud RW. Information technology implementation research: a technological diffusion approach. Management science 1990;36(2):123-139.

46. Coleman J, Katz E, Menzel H. The diffusion of an innovation among physicians. Sociometry 1957:253-270.

47. Ford EW, Menachemi N, Peterson LT, Huerta TR. Resistance is futile: but it is slowing the pace of EHR adoption nonetheless. J Am Med Inform Assoc 2009 May-Jun;16(3):274-281.

48. Ash JS, Sittig DF, Dykstra RH, Guappone K, Carpenter JD, Seshadri V. Categorizing the unintended sociotechnical consequences of computerized provider order entry. Int J Med Inform 2007 Jun;76 Suppl 1:21-27.

49. Klein L. What do we actually mean by 'sociotechnical'? On values, boundaries and the problems of language. Appl Ergon 2014 Mar;45(2):137-142.

50. Taylor,Frederick Winslow,,. The principles of scientific management. New York: Norton; 1967, ©1947.

51. Cherns A. The Principles of Sociotechnical Design1. Human relations 1976;29(8):783-792.

52. Clegg CW. Sociotechnical principles for system design. Appl Ergon 2000;31(5):463-477.

53. Jones SS, Heaton PS, Rudin RS, Schneider EC. Unraveling the IT productivity paradox--lessons for health care. N Engl J Med 2012 Jun 14;366(24):2243-2245.

54. Callen J, Georgiou A, Li J, Westbrook J. The Value of Sociotechnical Theories for Implementation of Clinical Information Systems. Inter-organizational Information Systems and Business Management: Theories for Researchers 2012:229.

55. Kannampallil TG, Schauer GF, Cohen T, Patel VL. Considering complexity in healthcare systems. J Biomed Inform 2011 12;44(6):943-947.

56. Sittig DF, Singh H. A new sociotechnical model for studying health information technology in complex adaptive healthcare systems Qual Saf Health Care 2010 Oct;19 Suppl 3:i68-74.

57. Perlman G. Answer(s) to G-1 2010; Available at: http://edgarmatias.com/faq/G/G-1.html. Accessed 5/7/2012, 2012.

58. Association for Computing Machinery.
ACM SIGCHI Curricula for Human-Computer Interaction. 1992, p. 5.

59. Agarwal R, Venkatesh V. Assessing a firm's web presence: a heuristic evaluation procedure for the measurement of usability. Information Systems Research June, 2002;13(2):168-186.

60. Nielsen J, Mack RP. Usability inspection methods New York: Wiley; 1994.

61. International Standards Organization. ISO 9241-11:1998 - Ergonomic requirements for office work with visual display terminals (VDTs) -- Part 11: Guidance on usability Available at: http://www.iso.org/iso/catalogue_detail.htm?csnumber=16883. Accessed 4/24/2013, 2013.

62. Whitefield A, Wilson F, Dowell J. A framework for human factors evaluation Behaviour & Information Technology 1991;10(1):65 <last_page> 79.

63. User interface evaluation in the real world: a comparison of four techniques. Proceedings of the SIGCHI conference on Human factors in computing systems: ACM; 1991.

64. Zhang J, Walji MF. TURF: Toward a unified framework of EHR usability. J Biomed Inform 2011 Aug 16.

65. Carroll JM, Rosson MB. Dimensions of participation in information systems design. Human-Computer Interaction and Management Information Systems: Foundations P.Zhang and D.Galletta (eds.).Armonk, NY: ME Sharp Inc 2006:337-354.

66. Kensing F, Blomberg J. Participatory design: Issues and concerns. Computer Supported Cooperative Work (CSCW) 1998;7(3-4):167-185.

67. Carroll JM. Encountering others: reciprocal openings in participatory design and user-centered design. Human–Computer Interaction 1996;11(3):285-290.

68. Creswell JW. Research design: qualitative, quantitative, and mixed methods approaches Thousand Oaks, Calif.: Sage Publications; 2009.

69. Greene JC, Caracelli VJ, Graham WF. Toward a Conceptual Framework for Mixed-Method Evaluation Designs. Educational Evaluation and Policy Analysis 1989 Autumn;11(3):255-274.

70. Rossman GB, Wilson BL. Numbers and Words Combining Quantitative and Qualitative Methods in a Single Large-Scale Evaluation Study. Eval Rev 1985;9(5):627-643.

71. Caracelli VJ, Greene JC. Data analysis strategies for mixed-method evaluation designs. Educational evaluation and policy analysis 1993;15(2):195-207.

72. Creswell DJW, Clark DC. Designing and Conducting Mixed Methods Research Second Edition ed.: Sage Publications, Inc; 2010.

73. Denzin NK. Symbolic interactionism. A companion to qualitative research 2004:81-87.

74. Corbin J, Strauss A. Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory. 3rd ed.: Sage Publications, Inc; 2007.

75. Webopedia. Search engine optimization (optimizer) - SEO. Available at: http://www.webopedia.com/TERM/S/SEO.html.

76. Merriam-Webster. Definition of optimization. Available at: http://www.merriam-webster.com/dictionary/optimization.

77. TheFreeDictionary. Optimization. Available at: http://www.thefreedictionary.com/optimization. Accessed 5/28, 2015.

78. Kohn Lea. To Err is Human : National Academy Press; 1999.

79. Institute of Medicine Committee on Quality of Health Care in America. Crossing the Quality Chasm: A New Health System for the 21st Century. 1st ed.: National Academies Press; 2001.

80. Safety,Committee on Data Standards for Patient. Patient Safety: Achieving a New Standard for Care. 1st ed.: National Academies Press; 2004.

81. HIMSS. HIMSS Definitions. .

82. Bates DW, Ebell M, Gotlieb E, Zapp J, Mullins HC. A proposal for electronic medical records in U.S. primary care. J Am Med Inform Assoc 2003 Jan-Feb;10(1):1-10.

83. Jha AK, Doolan D, Grandt D, Scott T, Bates DW. The use of health information technology in seven nations. Int J Med Inform 2008 Dec;77(12):848-854.

84. Bush G. Executive Order 13410: Promoting Quality and Efficient Health Care in Federal Government Administered or Sponsored Health Care Programs. 2006.

85. The White House. State of the Union. White House.gov Photo Gallery Feed 2010 Thu, 28 Jan.

86. Blumenthal D. Stimulating the adoption of health information technology. N Engl J Med 2009 Apr 9;360(15):1477-1479.

87. Lorenzi NM, Kouroubali A, Detmer DE, Bloomrosen M. How to successfully select and implement electronic health records (EHR) in small ambulatory practice settings. BMC Med Inform Decis Mak 2009 Feb 23;9:15.

88. Moore GA. Crossing the chasm : marketing and selling disruptive products to mainstream customers. Rev. ed. New York, NY: HarperBusiness Essentials; 2002.

89. Lorenzi NM. Strategies for creating successful local health information infrastructure Initiatives. 2003.

90. Lorenzi NM, Riley RT. Managing change: an overview. J Am Med Inform Assoc 2000 Mar-Apr;7(2):116-124.

91. Lorenzi NM, Riley RT. Organizational issues = change. Int J Med Inform 2003 Mar;69(2-3):197-203.

92. Hersh. Health care information technology: progress and barriers. JAMA - Journal of the American Medical Association 2004;292(18):2273.

93. Poon EG, Blumenthal D, Jaggi T, Honour MM, Bates DW, Kaushal R. Overcoming barriers to adopting and implementing computerized physician order entry systems in U.S. hospitals. Health Aff (Millwood) 2004 Jul-Aug;23(4):184-190.

94. Coye MJ, Kell J. How hospitals confront new technology. Health Aff (Millwood) 2006 Jan-Feb;25(1):163-173.

95. Glaser BG, Strauss AL editors. The discovery of grounded theory : strategies for qualitative research. Chicago: Aldine Pub. Co.; 1967.

96. Krueger RA. Focus groups : a practical guide for applied research. 2nd ed. ed. Thousand Oaks, Calif.: Sage Publications; 1994.

97. Ash JS, Berg M, Coiera E. Some unintended consequences of information technology in health care: the nature of patient care information system-related errors. J Am Med Inform Assoc 2004 Mar-Apr;11(2):104-112.

98. Ash JS, Sittig DF, Poon EG, Guappone K, Campbell E, Dykstra RH. The Extent and Importance of Unintended Consequences Related to Computerized Provider Order Entry. J Am Med Inform Assoc 2007 July-August;14(4):415-423.

99. Ash JS, Bates DW. Factors and forces affecting EHR system adoption: report of a 2004 ACMI discussion. J Am Med Inform Assoc 2005 Jan-Feb;12(1):8-12.

100. Ash JS, Sittig DF, Campbell E, Guappone K, Dykstra RH. An Unintended Consequence of CPOE Implementation: Shifts in Power, Control, and Autonomy. AMIA Annu Symp Proc 2006:11-15.

101. Sittig DF, Krall M, Kaalaas-Sittig J, Ash JS. Emotional aspects of computer-based provider order entry: a qualitative study. J Am Med Inform Assoc 2005 Sep-Oct;12(5):561-567.

102. Joos D, Chen Q, Jirjis J, Johnson KB. An electronic medical record in primary care: impact on satisfaction, work efficiency and clinic processes. AMIA Annu Symp Proc 2006:394-398.

103. O'Connell RT, Cho C, Shah N, Brown K, Shiffman RN. Take note(s): differential EHR satisfaction with two implementations under one roof. J Am Med Inform Assoc 2004 Jan-Feb;11(1):43-49.

104. Middleton B, Hammond WE, Brennan PF, Cooper GF. Accelerating U.S. EHR adoption: how to get there from here. recommendations based on the 2004 ACMI retreat. J Am Med Inform Assoc 2005 Jan-Feb;12(1):13-19.

105. Middleton B. Achieving US Health Information Technology Adoption: The Need For A Third Hand. < I> Health Affairs</I> 2005;24(5):1269.

106. van der Meijden MJ, Tange H, Troost J, Hasman A. Development and implementation of an EPR: how to encourage the user. Int J Med Inform 2001 Dec;64(2-3):173-185.

107. President's Council of Advisors on Science and Technology. Report to the President Realizing the Full Potential of Health Information Technology to Improve Healthcare for Americans: The Path Forward. 2010.

108. The White House. The White House - Press Office - Remarks of President Barack Obama -- Address to Joint Session of Congress. Available at: http://www.whitehouse.gov/the_press_office/Remarks-of-President-Barack-Obama-Address-to-Joint-Session-of-Congress/. Accessed 4/14/2009, 2009.

109. Koshy R. Navigating the information technology highway: computer solutions to reduce errors and enhance patient safety. Transfusion 2005 Oct;45(4 Suppl):189S-205S.

110. National Academy of Sciences. Key Capabilities of an Electronic Health Record. 2003.

111. Bates DW, Cohen M, Leape LL, Overhage JM, Shabot MM, Sheridan T. Reducing the frequency of errors in medicine using information technology. J Am Med Inform Assoc 2001 Jul-Aug;8(4):299-308.

112. Institute of Medicine Committee on Quality of Health Care in America. To Err Is Human: Building a Safer Health System. 1st ed.: National Academies Press; 2000.

113. Abdolrasulnia M, Menachemi N, Shewchuk RM, Ginter PM, Duncan WJ, Brooks RG. Market effects on electronic health record adoption by physicians. Health Care Manage Rev 2008 Jul-Sep;33(3):243-252.

114. Ford EW, Menachemi N, Phillips MT. Predicting the adoption of electronic health records by physicians: when will health care be paperless? J Am Med Inform Assoc 2006 Jan-Feb;13(1):106-112.

115. Geibert RC. Using diffusion of innovation concepts to enhance implementation of an electronic health record to support evidence-based practice. Nurs Adm Q 2006 Jul-Sep;30(3):203-210.

116. Poissant L, Pereira J, Tamblyn R, Kawasumi Y. The impact of electronic health records on time efficiency of physicians and nurses: a systematic review. J Am Med Inform Assoc 2005 Sep-Oct;12(5):505-516.

117. Menachemi N, Ford EW, Beitsch LM, Brooks RG. Incomplete EHR adoption: late uptake of patient safety and cost control functions. Am J Med Qual 2007 Sep-Oct;22(5):319-326.

118. Grabenbauer L, Fraser RS, McClay JC, Woelfl N, Thompson CB, Campbell J, et al. Adoption of Electronic Health Records: A Qualitative Study of Academic and Private Physicians and Health Administrators. Applied Clinical Informatics 2011:965.

119. Whitten J, Bentley L. Systems Analysis and Design Methods 7th ed.: McGraw-Hill/Irwin <SKU> 913464-A10-0073052337; 2005.

120. Halbesleben JR, Wakefield DS, Ward MM, Brokel J, Crandall D. The relationship between super users' attitudes and employee experiences with clinical information systems. Med Care Res Rev 2009 Feb;66(1):82-96.

121. Strauss AL, Corbin JM. Basics of qualitative research :grounded theory procedures and techniques. Newbury Park, Calif.: Sage Publications; 1991.

122. Scalzi T. The VA leads the way in electronic innovations. Nursing 2007 Sep;37(9):26-27.

123. Lovis C, Payne TH. Extending the VA CPRS electronic patient record order entry system using natural language processing techniques. Proc AMIA Symp 2000:517-521.

124. Centricity Enterprise - Healthcare IT Solutions - GE Healthcare Available at: https://www2.gehealthcare.com/portal/site/usen/menuitem.e8b305b80b84c1b4d6354a1074c84130/?vgnextoid=5b83e73922f30210VgnVCM10000024dd1403RCRD&vgnextfmt=default&productid=4b83e73922f30210VgnVCM10000024dd1403____. Accessed 7/6/2011, 2011.

125. Lincoln YS, Guba EG. Naturalistic Inquiry. 1st ed.: Sage Publications, Inc; 1985.

126. Miles MB, Huberman M. Qualitative Data Analysis: An Expanded Sourcebook 2nd ed.: Sage Publications, Inc; 1994.

127. UNMC Internal Documentation. Physician Workflow. 2008.

128. Malhotra S, Jordan D, Shortliffe E, Patel VL. Workflow modeling in critical care: piecing together your own puzzle. J Biomed Inform 2007 Apr;40(2):81-92.

129. McGrath JM, Arar NH, Pugh JA. The influence of electronic medical record usage on nonverbal communication in the medical interview. Health Informatics J 2007 Jun;13(2):105-118.

130. Solet DJ, Norvell JM, Rutan GH, Frankel RM. Lost in translation: challenges and opportunities in physician-to-physician communication during patient handoffs. Acad Med 2005 Dec;80(12):1094-1099.

131. Weir CR, Nebeker JR. Critical issues in an electronic documentation system. AMIA Annu Symp Proc 2007:786-790.

132. Javitt JC. How to succeed in health information technology. Health Aff (Millwood) 2004 Jan-Jun;Suppl Web Exclusives:W4-321-4.

133. Blumenthal D, Tavenner M. The "meaningful use" regulation for electronic health records. N Engl J Med 2010 Aug 5;363(6):501-504.

134. Center for Disease Control and Prevention. *National Hospital Ambulatory Medical Care Survey;2010 Emergency Department Summary*. Available at: http://www.cdc.gov/nchs/data/ahcd/nhamcs_emergency/2010_ed_web_tables.pdf. Accessed 5/22/2013, 2013.

135. Weininger M, Schoepf UJ, Ramachandra A, Fink C, Rowe GW, Costello P, et al. Adenosine-stress dynamic real-time myocardial perfusion CT and adenosine-stress first-pass dual-energy myocardial perfusion CT for the assessment of acute chest pain: Initial results. Eur J Radiol 2012 12;81(12):3703-3710.

136. Chen LM, Kennedy EH, Sales A, Hofer TP. Use of Health IT for Higher-Value Critical Care. N Engl J Med 2013 02/14; 2013/05;368(7):594-597.

137. Laxmisan A, Hakimzada F, Sayan OR, Green RA, Zhang J, Patel VL. The multitasking clinician: decision-making and cognitive demand during and after team handoffs in emergency care. Int J Med Inform 2007 Nov-Dec;76(11-12):801-811.

138. American College of Cardiology. CardioSource - Health IT Committee Available at: http://www.cardiosource.org/en/Advocacy/Issues/Health-Information-Technology/ACC-

Policies-and-Activities/Health-IT-Committee.aspx. Accessed 5/9/2013, 2013.

139. Middleton B, Bloomrosen M, Dente MA, Hashmat B, Koppel R, Overhage JM, et al. Enhancing patient safety and quality of care by improving the usability of electronic health record systems: recommendations from AMIA. J Am Med Inform Assoc 2013 Jan 25.

140. HIMSS EHR Usability Task Force. Defining and Testing EMR Usability: Principles and Proposed Methods of EMR Usability Evaluation and Rating. Available at: http://www.himss.org/content/files/HIMSS_DefiningandTestingEMRUsability.pdf. Accessed 2/19/2013, 2013.

141. Shneiderman B, Ben S. Designing The User Interface: Strategies for Effective Human-Computer Interaction, 4/e (New Edition). : Pearson Education India; 2003.

142. Lacerof A, Paterno F. Automatic support for usability evaluation. IEEE Transactions on Software Engineering 1998(24):863-867.

143. Testing a walkthrough methodology for theory-based design of walk-up-and-use interfaces. Proceedings of the SIGCHI conference on Human factors in computing systems: Empowering people: ACM; 1990.

144. Wharton C, Rieman J, Lewis C, Polson P,. The cognitive walkthrough method: A practitioner's guide. Usability Inspection Methods: John Wiley & Sons; 1994. p. 105-140.

145. Kushniruk AW, Patel VL, Cimino JJ. Usability testing in medical informatics: cognitive approaches to evaluation of information systems and user interfaces. Proc AMIA Annu Fall Symp 1997:218-222.

146. Usability evaluation with the cognitive walkthrough. Conference companion on Human factors in computing systems: ACM; 1995.

147. Holzinger A. Usability engineering methods for software developers. Commun ACM 2005;48(1):71-74.

148. Mahatody T, Sagar M, Kolski C. State of the Art on the Cognitive Walkthrough method, its variants and evolutions. Intl.Journal of Human–Computer Interaction 2010;26(8):741-785.

149. Lowry SZ, Quinn MT, Ramaiah M, Schumacher RM, Patterson ES, North R, et al. (NISTIR 7804) Technical Evaluation, Testing and Validation of the Usability of Electronic Health

Records. February 21, 2012.

150. Brooke J. SUS-A quick and dirty usability scale. Usability evaluation in industry 1996;189:194.

151. Morton ME, Wiedenbeck S. EHR acceptance factors in ambulatory care: a survey of physician perceptions. Perspect Health Inf Manag 2010 Jan 1;7:1c.

152. Ash JS, Sittig DF, Dykstra R, Campbell E, Guappone K. The unintended consequences of computerized provider order entry: findings from a mixed methods exploration. Int J Med Inform 2009 Apr;78 Suppl 1:S69-76.

153. Leech NL, Onwuegbuzie AJ. Beyond constant comparison qualitative data analysis: Using NVivo. School Psychology Quarterly 2011;26(1):70.

154. Ozkan BC. Using NVivo to analyze qualitative classroom data on constructivist learning environments. The qualitative report 2004;9(4):589-603.

155. Borsci S, Federici S, Lauriola M. On the dimensionality of the System Usability Scale: a test of alternative measurement models. Cogn Process 2009 Aug;10(3):193-197.

156. Lewis JR, Sauro J. The factor structure of the system usability scale. Human Centered Design: Springer; 2009. p. 94-103.

157. Meaningful Use Definition and Meaningful Use Objectives of EHRs | Providers & Professionals | HealthIT.gov; http://www.healthit.gov/providers-professionals/meaningful-use-definition-objectives; Accessed 8/6/2015, 2015.